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STUDIES OF DISPLAY SYMBOL LEGIBILITY

Part XV. Relative Legibility of Leroy and Teletypewriter Symbols

SEPTEMBER 1966

G. L. Bell

Prepared for
DEPUTY FOR ENGINEERING AND TECHNOLOGY
DECISION SCIENCES LABORATORY
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
L. G. Hanscom Field, Bedford, Massachusetts

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Project 7030

Prepared by
THE MITRE CORPORATION
Bedford, Massachusetts
Contract AF19(628)-5165

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FOREWORD

This report is one of a series describing symbol legibility for television display. Additional information on this topic may be found in the following reports: "Studies of Display Symbol Legibility: The Effects of Line Construction, Exposure Time, and Stroke Width," by B. Botha and D. Shurtleff, The MITRE Corp., Bedford, Mass., ESD-TR-63-249, February 1963; "Studies of Display Symbol Legibility, II: The Effects of the Ratio of Width of Inactive to Active Elements Within a TV Scan Line and the Scan Pattern Used in Symbol Construction," by B. Botha and D. Shurtleff, The MITRE Corp., Bedford, Mass., ESD-TR-63-440, July 1963; "Studies of Display Symbol Legibility, III: Line Scan Orientation Effects," by B. Botha, D. Shurtleff, and M. Young, The MITRE Corp., Bedford, Mass., ESD-TR-65-138, May 1966; "Studies of Display Symbol Legibility, IV: The Effects of Brightness, Letter Spacing, Symbol Background Relation, and Surround Brightness on the Legibility of Capitol Letters," by D. Shurtleff, B. Botha, and M. Young, The MITRE Corp., Bedford, Mass., ESD-TR-65-134, May 1966; "Studies of Display Symbol Legibility, V: The Effects of Television Transmission on the Legibility of the Common Five-Letter Words," by G. Kosmider, The MITRE Corp., Bedford, Mass., ESD-TR-65-135, May 1966; "Studies of Display Symbol Legibility, VI: Leroy and Courtney Symbols," by D. Shurtleff, and D. Owen, The MITRE Corp., Bedford, Mass., ESD-TR-65-136, May 1966; "Studies of Display Symbol Legibility, VII: Comparison of Displays at 945- and 525-Line Resolutions," by D. Shurtleff and D. Owen, The MITRE Corp., Bedford, Mass., ESD-TR-65-137, May 1966; "Studies of Display Symbol Legibility, VIII: Legibility of Common Five-Letter Words," by G. Kosmider, M. Young, and G. Kinney, The MITRE Corp., Bedford, Mass., ESD-TR-65-385, May 1966; "Studies of Display Symbol Legibility, IX: The Effects of Resolution, Size and Viewing Angle of Legibility," by D. Shurtleff, M. Marsetta, and D. Showman, The MITRE Corp., Bedford, Mass., ESD-TR-65-411, May 1966; "Studies of Display Symbol Legibility, X: The Relative Legibility of Leroy and Lincoln/MITRE Alphanumeric Symbols," by D. Showman, The MITRE Corp., Bedford, Mass., ESD-TR-66-115, August 1966; "Studies of Display Symbol Legibility, XI: The Relative Legibility of Selected Alphanumerics in Two Fonts," by G. Kinney and D. Showman, The MITRE Corp., Bedford, Mass., ESD-TR-66-116, August 1966; "Studies of Display Legibility, XII: The Legibility of Alphanumeric Symbols for Digitalized Television," by G. Kinney, M. Marsetta, and D. Showman, The MITRE Corp., Bedford, Mass., ESD-TR-66-117, August 1966; "Studies of Display Symbol Legibility, XIII: Studies of the Legibility of Alphanumeric Symbols in the BUIC Symbol," by G. Kinney and D. Showman, The MITRE Corp., Bedford, Mass., ESD-TR-66-302, August 1966; and "Studies in Display Symbol Legibility, XIV: The Legibility of

Military Map Symbols on Television," by M. Marsetta and D. Shurtleff, The MITRE Corp., Bedford, Mass., ESD-TR-66-315, September 1966.

ACKNOWLEDGMENTS

The author is indebted to many people for their help and encouragement. Dr. Richard Jones wrote much of the required computer program and assisted the author with the remainder. Dr. Charles V. Riche, Jr., provided a computer program for a statistical calculation. Miss Lyne Smith helped with the programming and the photographic work. Mrs. Diana Showman and Mrs. Marion Marsetta helped with the data collection. Mr. John Keating obtained the magnetic tapes and gave advice on the interpretation of weather data. Mr. Charles Urbon did the photography. Mrs. Jean Kierstead took charge of the artwork. The drawings of the teletype fonts were donated by Teletype Corporation, Skokie, Illinois. Mr. George Keyes and Mr. Robert Cisek of the Teletype Corporation provided technical information, as did Mr. Earl Brooks and Mr. Charles Theriault. The Data Processing Division of the Environmental Technical Applications Center, USAF, sent the magnetic tape recordings. Mr. Crist, Mr. Ramsey and Lieutenant C.W. Martinusen, Jr., of the Data Processing Division were most helpful. Major W. Johnson and Major T. Studer of the Weather Station, Hanscom Air Force Base, answered questions and supplied the hourly sequence reports.

In particular, the author is indebted to Dr. Glenn Kinney for his guidance throughout the work and for his help in writing this paper.

ABSTRACT

The first two studies are reported from a planned series of studies to obtain legibility data on teletyped hourly sequence weather reports. In the first study, subjects were asked to identify symbols, shown singly in a random order with the symbols occurring with equal frequencies. The two teletype fonts, Murray and Long Gothic, were compared with a standard Leroy font. The second study used the teletype fonts only, and the subjects identified symbols shown with symbol frequencies similar to those in typical hourly sequence reports. For these experimental conditions, the teletype fonts were not as legible as the standard Leroy font although the symbol frequencies found in typical hourly sequence reports improved the subjects' reading performances.

This is the final report of Project 7030.

REVIEW AND APPROVAL

This Technical Report has been reviewed and is approved.

JAMES D. BAKER
703 Project Officer
Decision Sciences Laboratory

ROY MORGAN
Colonel, USAF
Director, Decision Sciences Laboratory

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SECTION I

INTRODUCTION

One of the printed materials that is read and processed by operators in air defense and air traffic control systems is a teletyped weather report. The most frequently occurring report is the Hourly Sequence Report (HSR) which is made on the hour, every hour, at weather stations throughout the world. In the United States, as in many other places, the HSR is teletyped on yellow paper in standard codes and formats. The symbols are of two styles (or fonts), Long Gothic and Murray (see Figures 1 and 2). The legibility of the symbols in these two fonts is of interest, especially to designers of display systems who contemplate using closed-circuit television monitors to distribute the HSR to interested viewers.

The information on legibility of most value to the display designer is the relation between the viewer's ability to read the HSR rapidly and accurately and the resolution of the symbol on the monitor, usually expressed by the number of active TV lines per symbol height. Similar information on other symbols has been obtained,[1,2,3] and the same techniques are applicable to any font. The HSR, however, differs from other textual materials in its strict adherence to a fixed format and in the fact that some symbols occur far more frequently

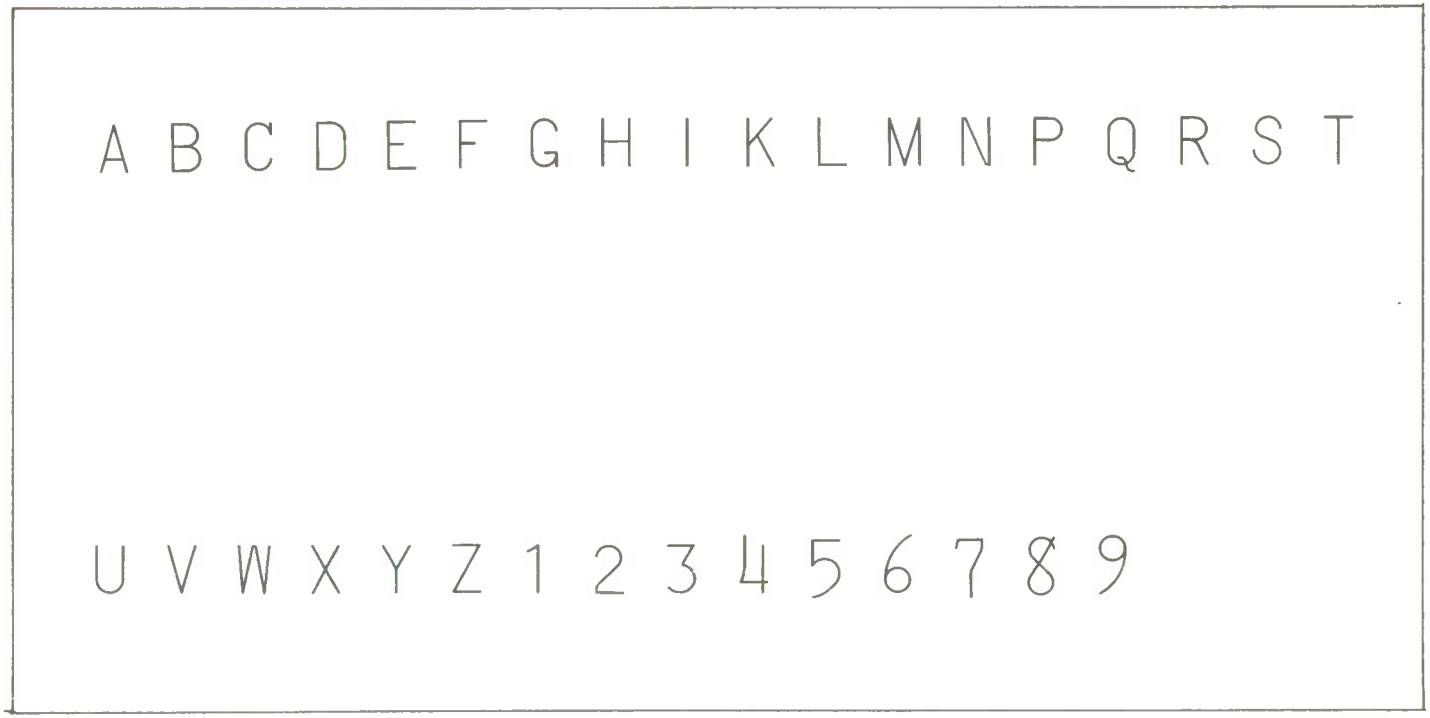


Figure 1. The Long Gothic Symbols Used in Experiments I and II

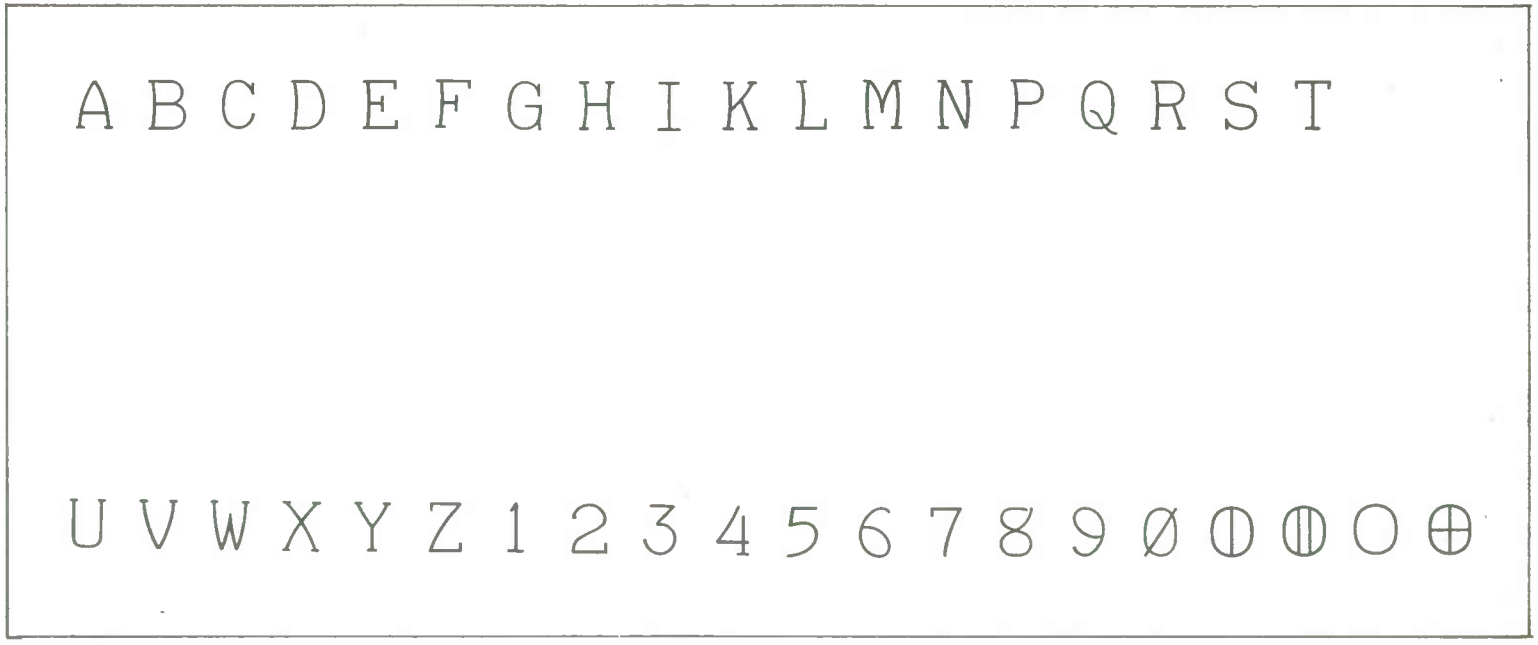


Figure 2. The Murray Symbols Used in Experiments I and II

than do others. Both the fixed format and the unequal frequencies of occurrence of symbols are commonly known to influence the reading performance of a viewer. Usually, this influence enables the viewer to perform well at resolutions and brightness contrasts where other unformatted and less redundant materials would be harmfully illegible. Therefore, the results of earlier studies on symbol legibility are not directly applicable to the HSR, which must be studied on its own. The results of these studies may then be related to those of similar studies, if this seems wise.

In these studies, the legibility of a font is measured by the accuracy with which viewers, having normal vision, can identify the symbols. In a display, the viewing conditions (symbol brightness, contrast with background, exposure time, size, etc.) may cause a viewer to make errors in identifying some symbols. With these conditions, some fonts may be easier to read accurately than others. One way in which the legibility of a font may be tested is to deteriorate the viewing conditions in a controlled laboratory experiment until viewers make some errors or take an excessively long time to identify some symbols.[4]* The resulting distribution of errors among the symbols may reveal consistent confusions. If some of the symbols are redesigned, it may be possible to improve the legibility of a font.

---

* See pages 1 and 2 in Reference 4.

Since the effects of a change in design are not always predictable, the legibility test should then be repeated for all the symbols in the font.[1,3]*

In the case of the HSR, the format and the unequal frequencies of symbol occurrence are two distinguishing features which have effects on reading performance which may also be studied in a laboratory setting. A sequence of studies that reveals different effects in a systematic order would begin with a comparison of Long Gothic and Murray symbols with the symbols of a font known to have good legibility, such as standard Leroy (see Figures 3 and 4). This first study would be done with excellent viewing conditions, except for the duration of exposure, and with equal frequency of occurrence of symbols. The second study would retain the same conditions, except that the frequency of symbol occurrence would closely approximate the distribution found in the HSR. This paper reports the first two studies in the series. The third and fourth studies would repeat the first two except that the symbols would be seen on a TV monitor with various resolutions. The fifth and sixth studies would be done with the formatted HSR viewed directly and on TV. Possible seventh and eighth studies would repeat studies five and six, except that the subjects would be highly experienced personnel who are familiar with the HSR format. These studies should provide the system

---

* See page 3 in Reference 1 and pages 1 and 6 in Reference 3.

Figure 3. Narrow-Stroke Leroy Symbols With Modified I and Ø

Figure 4. Wide-Stroke Leroy Symbols With Modified I and Ø

user with the specific information he needs to optimize display legibility and capacity at the same time.

There are other results from such a study series that are of more general value. The effects of unequal frequency of symbol occurrence on the speed and accuracy of symbol identification have general interest in the study of man/machine communications. The effects on legibility of display by TV have widespread interest, especially if there is an interaction between symbol frequency distribution and mode of display (direct viewing and TV display being the two modes). Finally, there are possible benefits of viewer familiarity and experience which permit the designer to use lower-than-ordinary resolution and clarity, thus increasing display capacity.

For the first two studies in the series, one of the manufacturers of teletype machines (Teletype Corporation) was asked for information about the symbol fonts on the machines of the HSR circuits. Both the military and the civilian users specify Teletype Corporation's model 28 machine. The military teletype printers have type pallets (the part with the symbol embossed on it which prints the symbol) of the Long Gothic font for the alphanumeric symbols, plus five type pallets of the Murray font for the zero and the four weather (or cloud-cover) symbols ○, ◔, ◑, and ⊕, (called clear, scattered, broken, and overcast).

This combination of the two fonts will be called the Long Gothic font in this paper. The civilian teletype printers have type pallets of the Murray font for all of the symbols.

The first study compared the legibility of the Murray and Long Gothic fonts with a standard Leroy font which is known to have good legibility. All the fonts were seen with an equal frequency of occurrence of the symbols and with good viewing conditions except for the exposure time. These conditions were obtained with a tachistoscope using photographed 'ideal' symbols as the stimuli. By 'ideal' symbols, it is meant that each symbol has sharply defined edges and all the symbols of one font have a uniform height and stroke-width. The comparisons between the fonts were made at three symbol brightness values with the same short exposure time of the symbols at each brightness. It was found that decreasing the brightness had less effect on each viewer's ability to identify symbols in the Leroy font than in the Murray or Long Gothic fonts. Also, the Long Gothic font was the least legible of the three fonts.

The second study compared the Long Gothic with the Murray font under the same viewing conditions as the first study, but with the frequency of symbol occurrence as found in the HSR's from Westover Air Force Base. Appendix I describes how this Westover frequency distribution was obtained. The occurrence of certain symbols in the

HSR's depends, of course, on the weather conditions being reported. These conditions vary with the seasons and the geographical areas. Westover Air Force Base was selected for counting the frequency of occurrence of the symbols in HSR's because it is in an area which experiences many different seasonal weather conditions over the year. The second study showed that, at the lowest brightness value and with the Westover frequency of symbol occurrence, the percent error in identifying the symbols was less than half that in the first study.

From the results of these first two studies, the legibility of both the Long Gothic and the Murray fonts should be improved by redesigning the four weather symbols and some of the alphanumeric symbols. Changes in the design of the weather symbols are discussed later. Changes in the design of the alphanumeric symbols to make them similar to those of the Lincoln/MITRE symbols[4] would probably improve their legibility.

SECTION II

EXPERIMENT I

In this experiment, the legibilities of the Murray and Long Gothic fonts were compared with a standard Leroy font, with the symbols in each font appearing with equal frequency. To compare the legibility of different fonts, the symbol sizes and stroke-widths should be similar because stroke-width affects legibility.[5,6] Both the Long Gothic and Murray fonts have a narrow stroke-width. The stroke-width of the standard Leroy font, which was compared to the Long Gothic and Murray fonts, was reduced to make the symbol size and stroke-width the same for all three fonts. This narrow-stroke Leroy will be called the N-S Leroy font in this paper (see Figure 3), and a standard Leroy font with a 6 to 1 ratio of symbol height to stroke-width will be called the wide-stroke, or W-S Leroy font (see Figure 4). An earlier experiment with W-S Leroy[4] had been done under the same conditions as this first study with the exception that the symbol brightness settings were 10, 8, 6, and 4 foot-Lamberts. A comparison of the results for the W-S and N-S Leroy fonts will indicate differences in legibility due to the stroke-width of the symbols.

APPARATUS AND PROCEDURE

The symbols were displayed to the subjects in the tachistoscope shown in Figure 5. This device was a T-shaped tube of rectangular

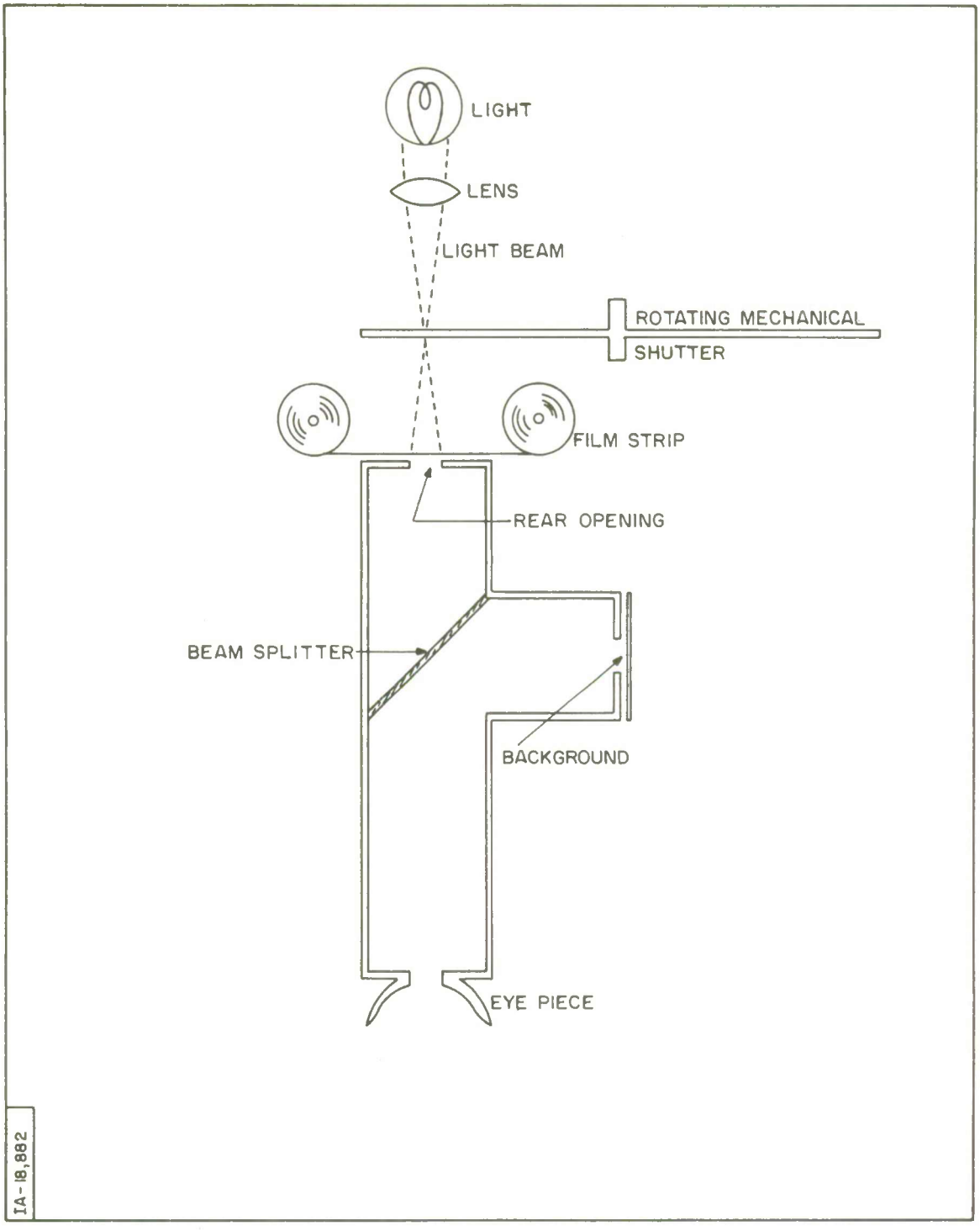


Figure 5. The Tachistoscope

cross-section (4 x 6 1/2 inches) arranged so that the subject could peer into one end of the cross of the T to see the other end at a distance of 54 inches. A beam splitter was mounted in the tube at the intersection of the cross and stem of the T to reflect the image of the base of the stem and to transmit the image of the opposite end of the cross at the same time. The two end spaces were thus superimposed and at the same apparent distance from the subject's eyes. There was a 1/2-inch diameter hole in the center of the far end of the cross of the T. A 35 mm film strip of the symbols was positioned behind this hole and was lighted from behind by a battery-powered, incandescent lamp. The subject saw a single symbol on the film strip when he looked through the tachistoscope eyepiece with the light-shutter open. For the film strips used in this experiment, the symbols subtended an angle of approximately 16 minutes of arc at the subject's eyes.

The end of the stem of the T was covered with a piece of fine-grained, white, styrofoam plastic (2 1/2 x 4 inches) which was lighted continuously by an incandescent lamp. This served as the background for the symbols. Four strips of black tape were glued to the plastic in the shape of a plus sign with its center removed. The center of the plus sign was visually coincident with the hole for the film strip and showed the subject where to focus his eyes in preparation for seeing the symbol.

The brightness of the background was varied with a Variac. The brightness of the symbol was varied by an iris diaphragm between the light and the film strip. All of the brightness measurements were made with a calibrated Spectra Brightness Spot Meter mounted at the eyepiece end of the tachistoscope.

The film strips of the symbols were made at MITRE from scale drawings of the Murray and Long Gothic type pallets donated by the Teletype Corporation. The scale of these drawings was not given, but the ratio of the height of the Murray T to the height of the Long Gothic T is 0.81. The technical data sheet for Teletype Corporation's model 28 machine gave the heights of the Murray and Long Gothic letters as 0.103 inch and 0.120 inch, giving a ratio of 0.86. It was assumed, therefore, that the two sets of drawings were made to the same scale. No adjustments were made to the letter heights in producing the film strip for the Long Gothic font from the combination of the Long Gothic and Murray drawings.

The drawings of the Long Gothic font were uniform in height and stroke-width. The ratio of the height to the stroke-width was approximately 18 to 1. The drawings of the Murray font were uniform in height, but not in stroke-width. This nonuniformity in the stroke-width was assumed to be an error and the Graphic Arts department in MITRE traced

the Murray drawings and made each symbol with the stroke-width of the original drawing of the Murray T. The ratio of the height to the stroke-width was approximately 17 to 1 for these redrawn Murray symbols.

The Graphic Arts department drew a set of standard Leroy symbols from a template. The I and Ø were modified, as shown in Figure 3, to distinguish them from the numeral 1 and the letter O, respectively. These Leroy symbols were uniform in height and stroke-width with the ratio of the height to the stroke-width approximately 20 to 1. This is the narrow-stroke (N-S) Leroy font mentioned earlier.

The Photo Laboratory made three film strips using a 35 mm DuPont Cronar-Ortho A Litho film. One film strip had N-S Leroy symbols, one had all Murray symbols, and the third had the combination of Murray and Long Gothic symbols that make up the Long Gothic font.

All three film strips had clear symbols of 1/4 inch height on a dark background. On the Long Gothic film strip, the ratio of the heights of the Murray weather symbols to the heights of the Long Gothic symbols was 0.87, which is comparable to the ratio of 0.86 given on Teletype Corporation's technical data sheet. The ratios for the height to the stroke-width of the symbols was 16 to 1 on the Murray, and 19 to 1 on the N-S Leroy film strip. On the Long Gothic film strip, the Long Gothic symbols had a ratio of height to stroke-width of 18 to 1, and the Murray symbols had a ratio of 16 to 1. The differences between

the film strips and the original drawings were due to the photographic processing of the film strips. The Photo Laboratory had experimented with the timing and temperature of the film processing until the symbol size ratios were considered to be sufficiently close to those of the original drawings.

The particular symbols on the film strips are those which may occur in the weather section of the HSR, which is itself written in a code called the "teletype code." This code is made up with all of the alphabet except J and O, all of the numerals including zero, and the four weather symbols ○, ⊙, ⊙, and ⊕. The Murray and Long Gothic film strips had only those symbols used in the teletype code; that is, the J and O were not on these two film strips. Both film strips were photographed so that the strip could be moved one frame at a time to present the symbols in a random order for a total of five presentations of each symbol in the complete film strip. These two film strips each had a total of 190 frames. A random order was produced by writing the 190 symbols on cards and shuffling the cards before drawing them one at a time without replacement.

The standard Leroy font does not contain any weather symbols, and the N-S Leroy film strip was made up with the complete alphabet and the numerals including zero. Each symbol occurred five times on the complete film strip making a total of 180 frames. A random sequence

of occurrence of the symbols along the film strip was produced in the same way as with the other two strips.

The experiment was done with three subjects whose visual acuity had been tested on a Bausch and Lomb Ortho-Rater and found normal. The tachistoscope was modified after the experiment had started and parts of the experiment had to be repeated. This meant that the subjects were practiced with all three fonts before the actual experiment was performed. All three subjects had taken part in other experiments using the tachistoscope, and some of these other experiments had been with a standard Leroy font of wider stroke than that used in this experiment.

The brightness of the background in the tachistoscope (the white, styrofoam plastic) was kept at 1 foot-Lambert throughout the experiment with no variation from this value observable on the Spectra Brightness Spot Meter. The brightness of the symbol was measured as the total brightness of the background plus the light being transmitted through a clear area of the film strip at either end of the sequence of frames. This total brightness was measured before and after each experimental session. The experiment was made at three values of symbol brightness. The total brightness (including the background) was set to 8 foot-Lamberts, 6 foot-Lamberts, and 5 foot-Lamberts giving brightness-contrast

ratios of 8 to 1, 6 to 1, and 5 to 1. The total brightness did not vary more than $\pm$ 0.2 foot-Lambert from these values. Each film strip was used at each brightness value making a total of nine sessions for each subject.

The experiment was started with the 8-foot-Lambert brightness value for all three film strips. The brightness value was then reduced to 6 foot-Lamberts for all three film strips, and then again reduced to 5 foot-Lamberts for the three film strips. Each session lasted approximately 15 minutes, and not more than two sessions for any one subject were run in one day.

The symbols were shown one at a time and the order in which they were shown was varied for each session so that no subject saw the same sequence of symbols more than twice, and therefore could not anticipate the occurrence of the symbols. The subject controlled the onset of presentation of the symbols by pressing a switch connected to the light-shutter mechanism. The symbols were exposed for 10 milliseconds and the subject called out his identification of the symbol shown, naming a symbol for each exposure. The symbol shown and the symbol called by the subject were recorded. The subject had a short, one-minute rest period after a group of 45 symbols had been seen, giving three rest periods per session. For each session, a photographic

print of the symbols in the font being shown was given to the subject, who could refer to this at any time. The subject was told, at the beginning of a session, that if he called out J or O for the Murray or Long Gothic symbols, he would be reminded that these symbols were not present and would be asked to make a choice from the set in the print for that session.

RESULTS AND CONCLUSIONS

The purpose of this first study was to compare the Long Gothic and Murray fonts with a standard Leroy font called the W-S Leroy font in this paper. In order to see the effects of a difference in the symbols' stroke-widths on the legibility of a font, the W-S Leroy was compared with the N-S Leroy font. The results for the W-S Leroy font were taken from an earlier study,[4] and the results for the N-S Leroy font were taken from this study. The viewing conditions were the same for both studies but, as mentioned earlier, the W-S Leroy study had nine subjects and this N-S Leroy study had three subjects. The total number of errors made at each brightness level was calculated, therefore, as a percentage value. Figure 6 is a graph of the percent error plotted against the symbol brightness. It can be seen that the W-S Leroy had a smaller percent error.

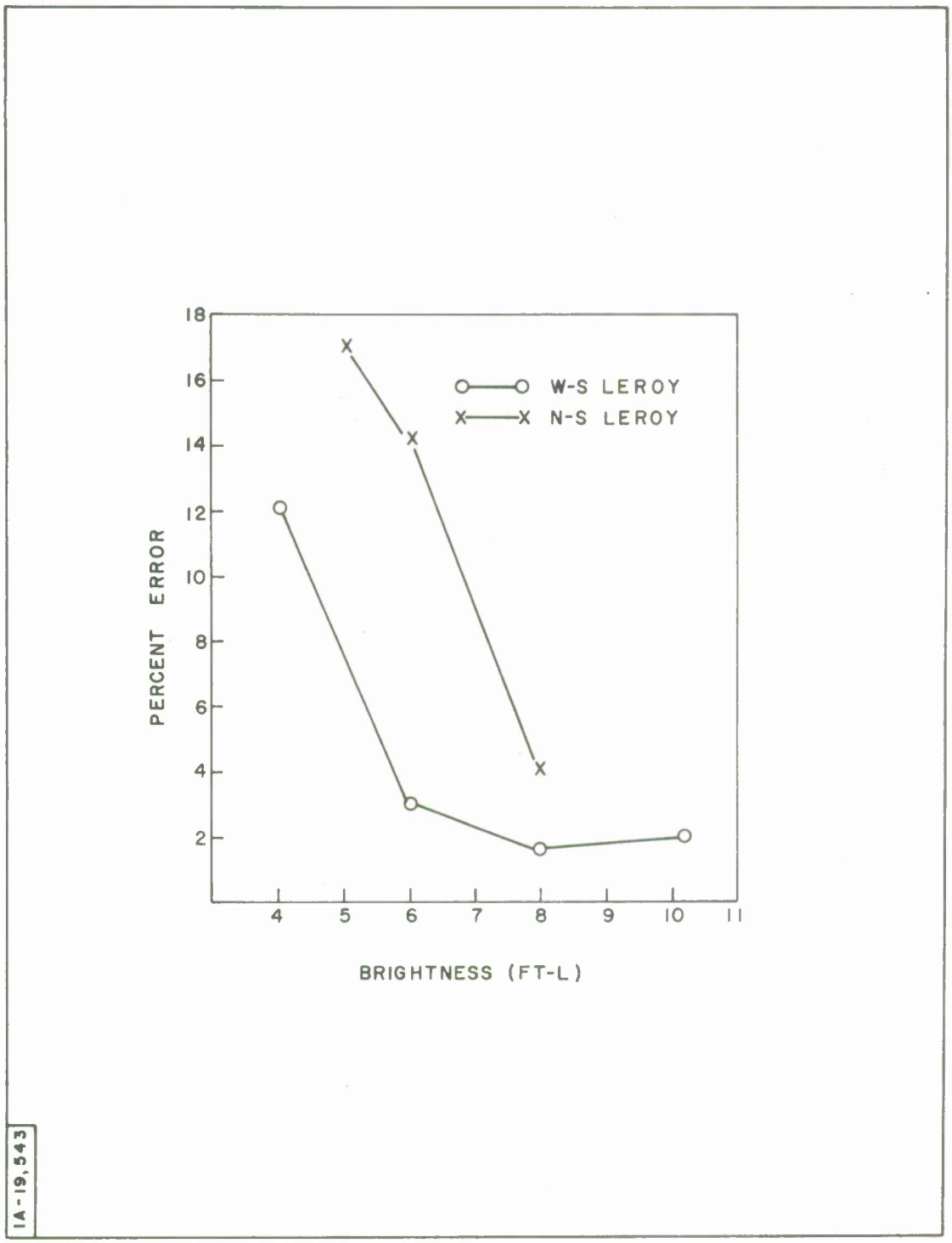


Figure 6. Percent Error for the W-S Leroy and N-S Leroy Fonts With Symbols Occurring With Equal Frequency

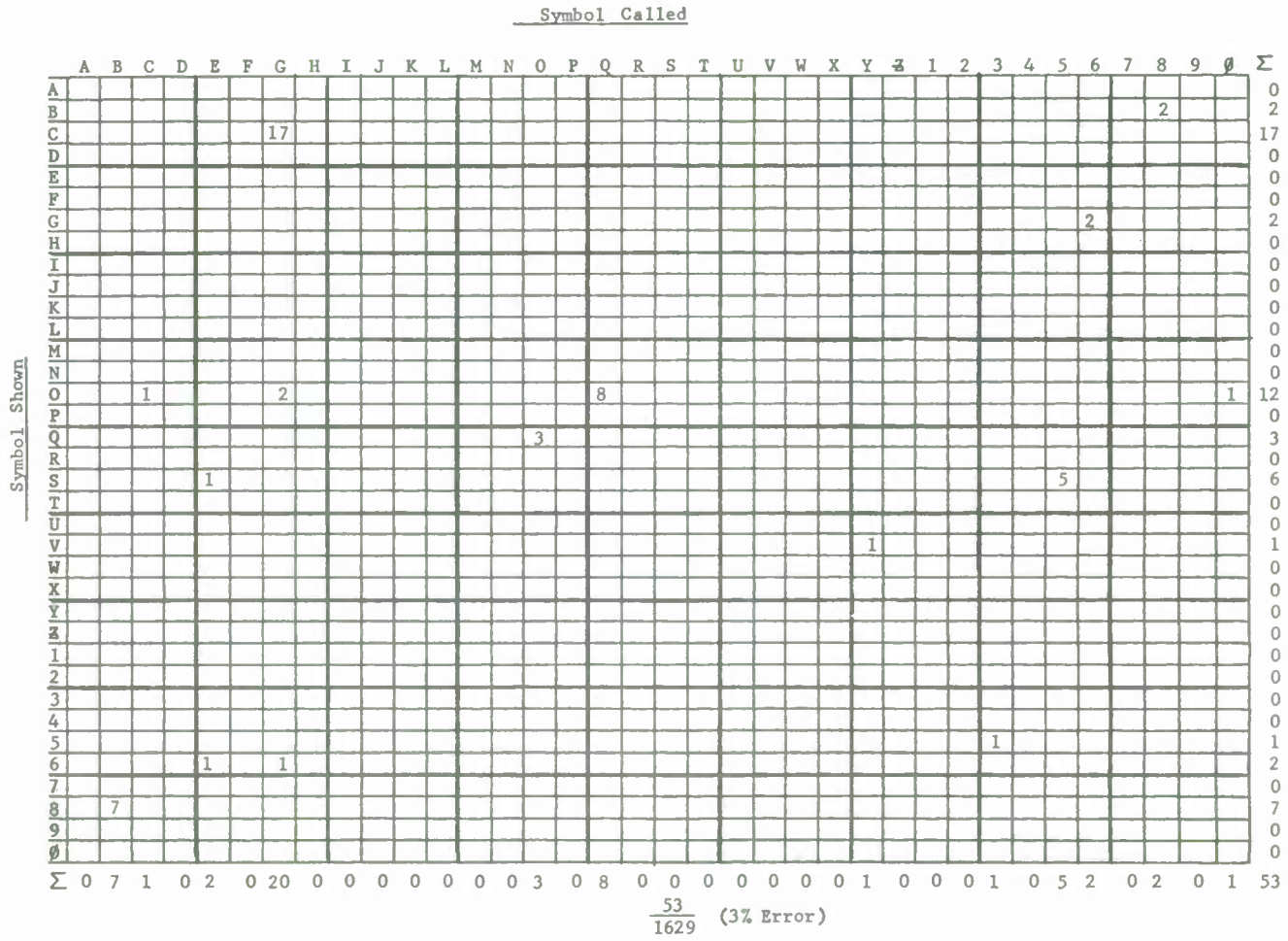
Another way to compare the two fonts was to look at the distribution of the errors among the symbols. Table I is the confusion matrix for the W-S Leroy font at 6-foot-Lambert symbol brightness, reproduced from the earlier study.[4] Table II is the confusion matrix for the N-S Leroy font at 6-foot-Lambert symbol brightness made in this study. The confusion matrices show the errors made by the subjects; that is, the entries give the number of times a symbol was called in error for each symbol shown. Comparing Tables I and II shows that the errors in the W-S Leroy font were concentrated in fewer symbols than the errors in the N-S Leroy font, showing the greater overall illegibility of the N-S Leroy font.

To summarize, the N-S Leroy font had a higher percentage of errors and these errors were more widely distributed among the symbols than were the errors in the W-S Leroy font. Thus, the N-S Leroy was not as legible as the W-S Leroy font when the symbols occurred with equal frequencies. This is in agreement with previous studies on symbol stroke-widths.[5,6]

Having seen the effects of symbol stroke-width on a font's legibility, the next part of this present study was to compare the Long Gothic and Murray fonts with the N-S Leroy font since these three fonts have approximately the same symbol stroke-width. The total number of errors made by the three subjects for the N-S Leroy, Long Gothic, and Murray fonts at the three brightnesses is given in Table III. (For

Table I

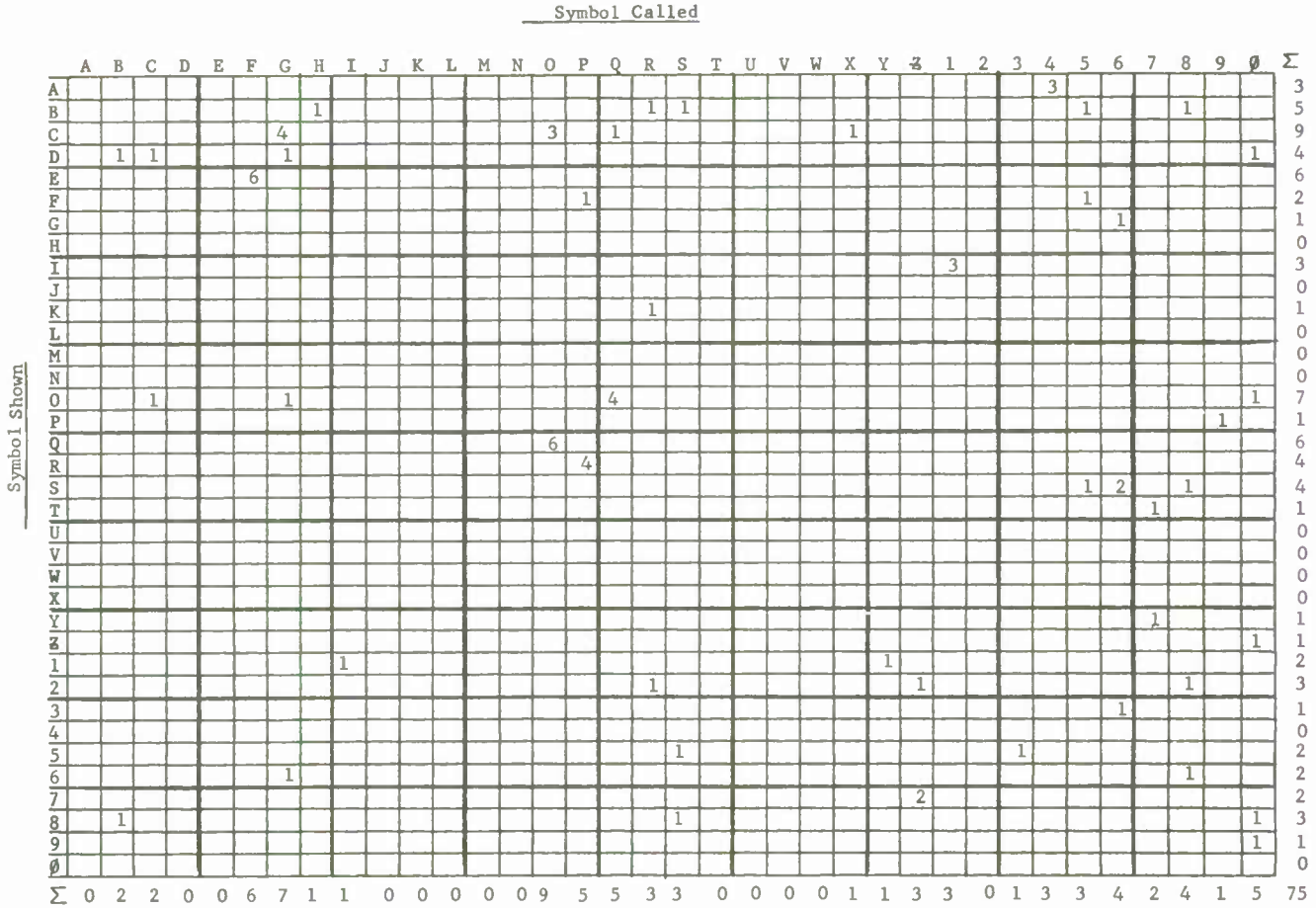
W-S Leroy at 6 Foot-Lamberts Symbol Brightness* (9 Subjects)



* Reproduced from experiment given in Reference 4.

Table II

N-S Leroy at 6 Foot-Lamberts Symbol Brightness (3 Subjects)



$\frac{75}{540}$ (14% Error)

Table III

The Total Number of Errors Made by all Three Subjects for all Three Fonts and Brightnesses With Symbols Occurring With Equal Frequencies (The total number of symbols shown at each brightness was 540 for N-S Leroy and 570 for Long Gothic and Murray.)

Foot-Lamberts	N-S Leroy	Long Gothic	Murray
8	24	21	18
6	75	86	61
5	90	155	129
Σ	189	262	208

each entry in the N-S Leroy column, the number of errors is from the 540 symbols shown to the subjects, and for each entry in the Long Gothic and Murray columns, the number of errors is from the 570 symbols shown to the subjects.) The total number of errors (189, 262, 208) taken as a percentage of the total number of symbols shown (1620, 1710, 1710) gives approximately 12 percent, 15 percent and 12 percent for the N-S Leroy, Long Gothic and Murray fonts. The total error, therefore, was about the same for the three fonts.

> Conclusion 1. It is concluded that the Long Gothic and Murray fonts are less legible than a standard Leroy font (W-S Leroy) since they appear to be no better than the N-S Leroy font.

Other analyses of the data are possible. Referring to Table III, it can be seen that the increase in the number of errors from the 8 foot-Lambert to the 5 foot-Lambert brightness was about 4 times for the N-S Leroy font and about 7 times for the Long Gothic and Murray fonts. This indicated that the N-S Leroy font was less affected by the decrease in brightness than were the Long Gothic and Murray fonts. To test the hypothesis that the increase in the number of errors with decreasing brightness was the same for each of the three fonts, a χ^2 test was made on the nine entries of Table III. This was statistically significant

($\chi^2 = 9.89, p < 0.05$) and, again, indicates that the increase in the number of errors with a decrease in brightness was less for the N-S Leroy font than for the Long Gothic and Murray fonts. This effect is shown more clearly in Figure 7, where the three solid-line curves show the percentage of the errors for the three fonts as tested in this first study. (The dashed-line curves are based on results obtained in the second study and will be referred to later.)

> Conclusion 2. It is concluded that the N-S Leroy font is less affected by a decrease in symbol brightness than are the Long Gothic and Murray fonts. Therefore, both the Long Gothic and Murray fonts are not acceptably legible if the viewing condition (symbol brightness) is poor.

It is of interest to see how the errors were distributed in each font, and the confusion matrices showing the error distributions at the 5 foot-Lamberts brightness setting are given in Tables IV, V, and VI. (Remember that the Long Gothic and Murray fonts were made up with a different set of symbols than was the N-S Leroy font.) Tables V and VI show that there were many errors associated with the weather symbols, 20 percent of the errors in the Long Gothic font and 22 percent of the errors in the Murray font. (The N-S Leroy font does not contain weather symbols.)

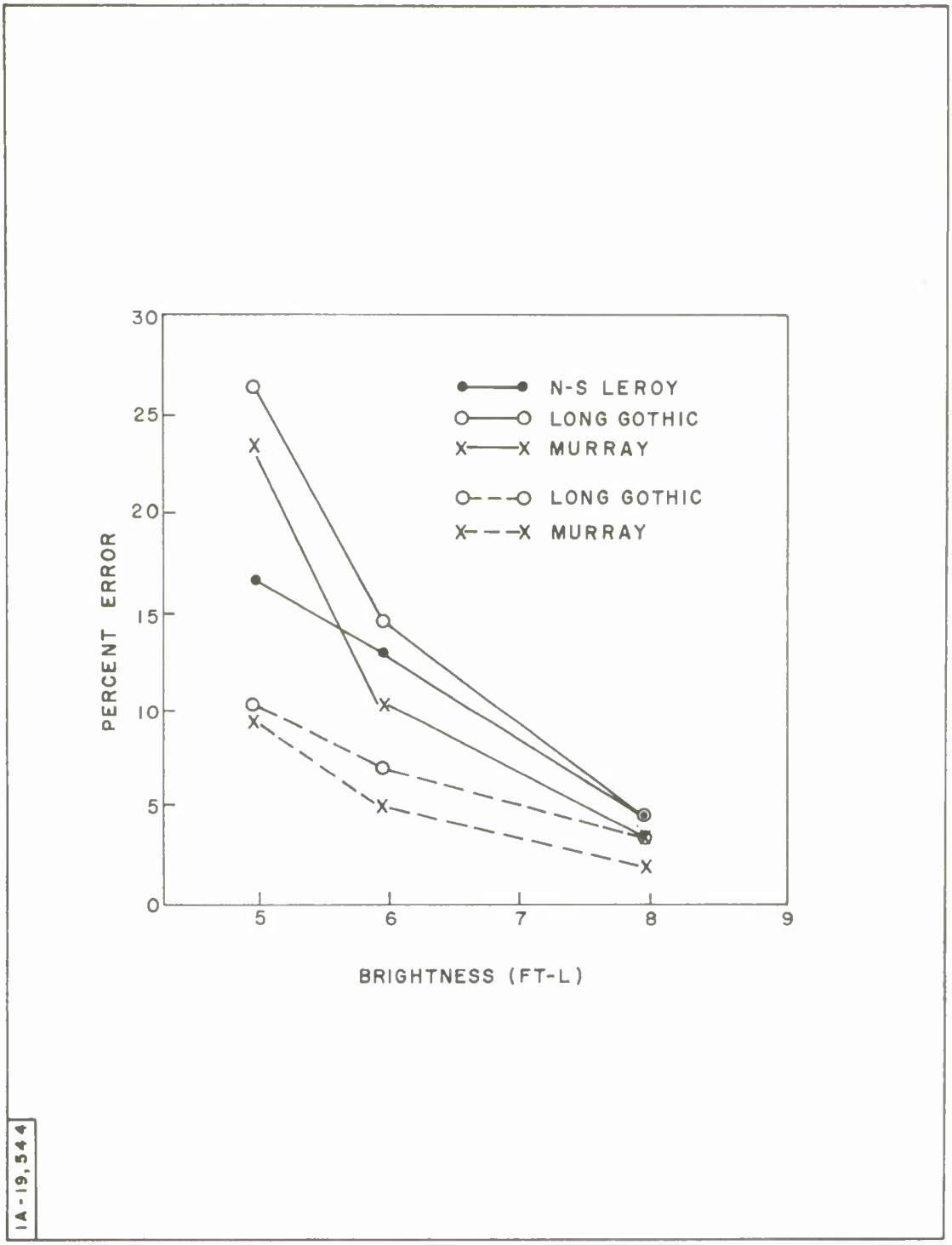


Figure 7. Percent Errors for the Three Fonts With Symbols Occurring With Equal Frequency and for the Two Fonts With Symbols Occurring with Westover Frequency

Table IV

N-S Leroy at 5 Foot-Lamberts Symbol Brightness (3 Subjects)

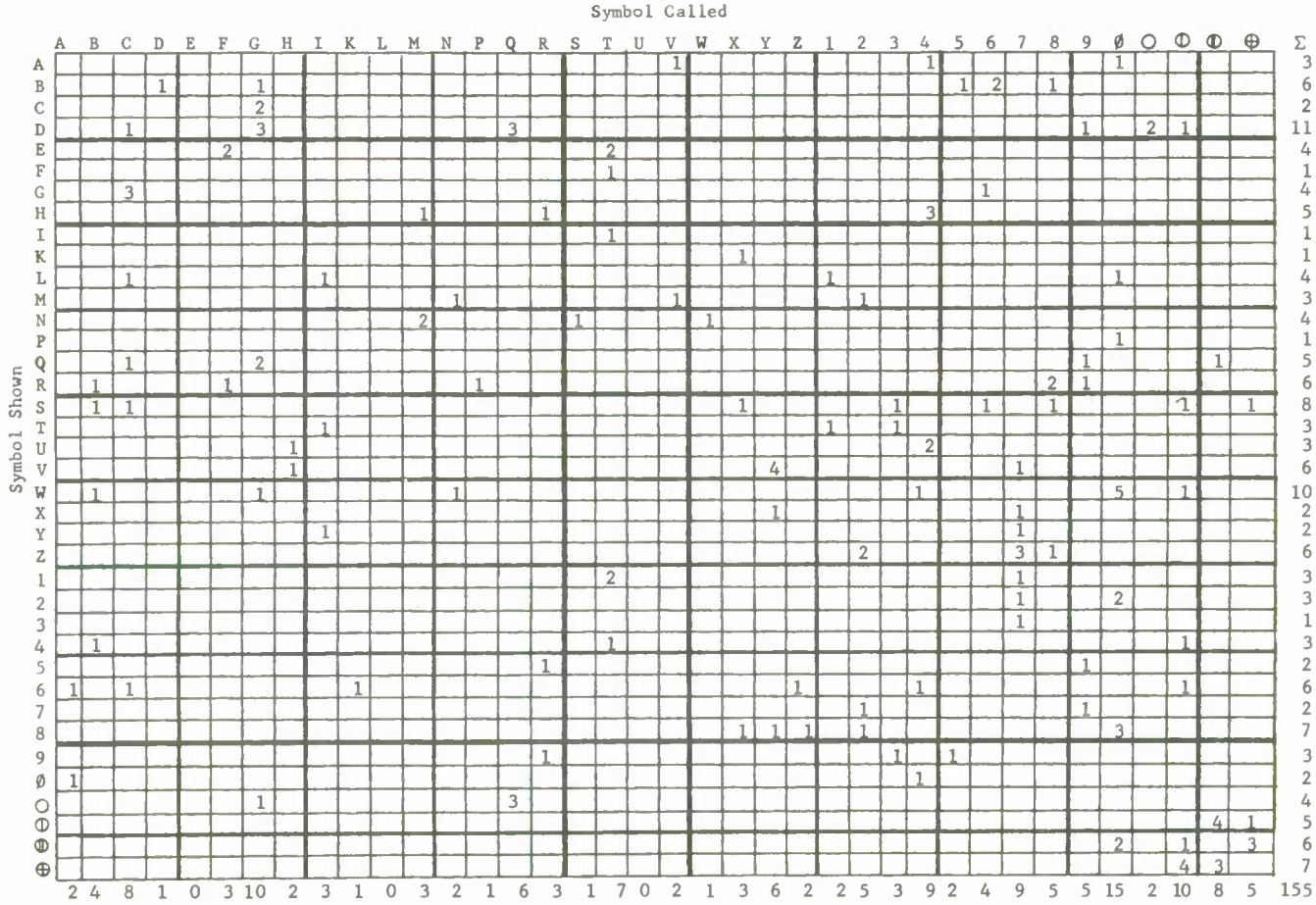
Symbol Called

Symbol Shown	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	1	2	3	4	5	6	7	8	9	Ø	Σ
A																																					0
B														1																		1			3	1		6
C							5								1																						2	8
D							1								2																							3
E						7																																7
F																															1						1
G			1																											1		2					4
H	1																																				1
I																											5										5
J																													1								1
K																		1																		1	2
L																																					0
M																																					0
N													1																									1
O							2										3																		1		6
P						1												1																			2
Q			2												7																						9
R		1														1																					2
S																															2	1					3
T																																					0
U														1																							1
V																								2													2
W														1																							1
X																																					0
Y														1																							1
Z																													1				2				3
1									2																1												3
2																										2										1	3
3															1																						1
4																																					0
5																																2					2
6							2																														2
7																																					0
8	1	4					1																														6
9	1																												2							1	4
Ø																																					0
Σ	3	5	3	0	0	8	11	0	2	0	0	0	1	4	11	1	3	2	0	0	0	0	0	2	1	2	5	0	4	1	3	6	2	3	2	5	90

$\frac{90}{540}$ (17% Error)

Table V

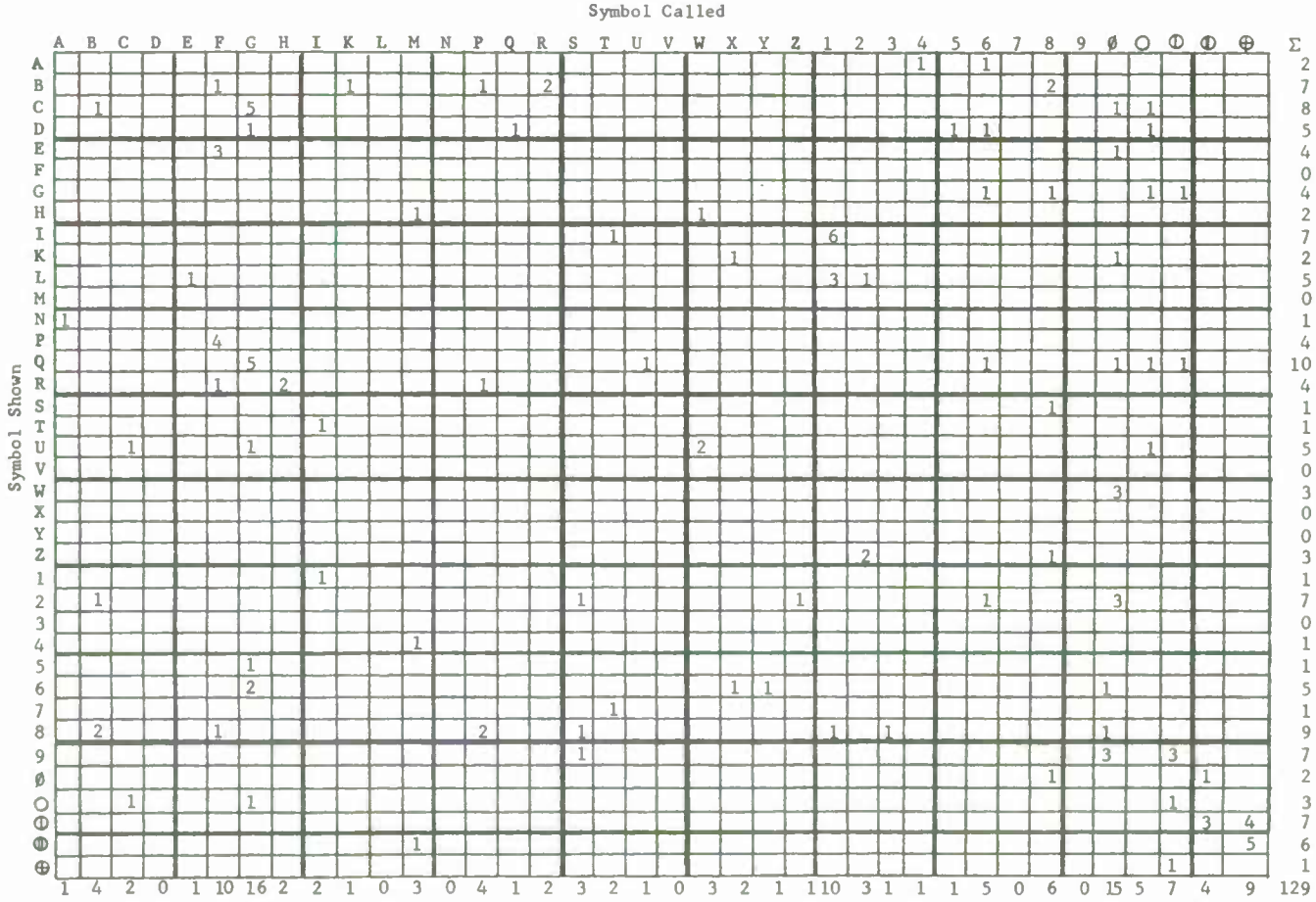
Long Gothic at 5 Foot-Lamberts Symbol Brightness (3 Subjects)



$\frac{155}{570}$ (27% Error)

Table VI

Murray at 5 Foot-Lamberts Symbol Brightness (3 Subjects)



$\frac{129}{570}$ (23% Error)

Conclusion 3. It is concluded that the four weather symbols are not acceptably legible and must be redesigned. This will be discussed later.

Having concluded that the weather symbols contributed a great many errors to the results of the tests on the Long Gothic and Murray fonts, it is of interest to re-examine these fonts by estimating the errors associated only with the alphanumeric symbols. This estimate was made by subtracting the errors associated with the four weather symbols from the number of errors made in the Long Gothic and Murray fonts, and by subtracting the errors associated with the J and O from the number of errors made in the N-S Leroy font. The numbers of errors remaining are given in Table VII and these errors are now from the same set of alphanumeric symbols in all three fonts. That is, for each of the nine entries in Table VII, the number of errors was from a total of 510 symbols shown. To test the hypothesis that the errors were distributed equally among the three fonts, when the fonts all contain the same symbols, a χ^2 test was made on the three sums (150, 201, 163). The χ^2 was statistically significant (χ^2 8·20, $p < 0.025$) and indicates that the errors were not distributed equally among the fonts. From inspection of Table VII, it is clear that the Long Gothic font had more errors than the N-S Leroy and Murray fonts.

Table VII

The Total Number of Errors of Table III Adjusted For Symbol Differences as Discussed in the Text (The total number of symbols shown at each brightness value was 510 for all three fonts.)

Foot-Lamberts	N-S Leroy	Long Gothic	Murray
8	19	12	14
6	59	65	48
5	72	124	101
Σ	150	201	163

Conclusion 4. For alphanumeric symbols appearing with equal frequency, it is concluded that the Long Gothic font is less legible than the Murray and N-S Leroy fonts.

Inspection of Table VII shows that there was an increase in the number of errors with decreasing symbol brightness for all three fonts. The hypothesis that the decrease in legibility with decreasing brightness was the same for the three fonts, when they all contain the same set of symbols, was tested by a χ^2 test of the nine entries of Table VII. This χ^2 was statistically significant ($\chi^2 = 11.00$, $p < 0.05$) and indicates that the N-S Leroy font was less affected by decreasing the symbol brightness than were the Murray and Long Gothic fonts.

Conclusion 5. It is concluded that the alphanumeric symbols in the N-S Leroy font are less affected by a decrease in symbol brightness than are the alphanumeric symbols in the Long Gothic and Murray fonts. The Long Gothic and Murray fonts are not acceptably legible, even for general use, when weather symbols are not used. (See the discussion section which follows.)

DISCUSSION AND RECOMMENDATIONS

There is some question about the validity of the adjustment of the entries in Table III to get those in Table VII. Nevertheless, the conclusions drawn seem reasonable when compared with those of previous experiments because the magnitude of the error and the distributions of errors in the matrices are comparable and similar to those found with other, similarly conventional fonts.[7,8,9]*

Since the Murray and Long Gothic fonts were less legible than the N-S Leroy font, which is itself less than acceptably legible, a redesign of the two fonts is clearly indicated. Recommendations for redesigning these fonts will be discussed after the results from the second study.

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* See page 10 in Reference 7, and page 13 in Reference 8.

SECTION III

EXPERIMENT II

It was mentioned earlier that an unequal frequency of occurrence of the symbols could influence the reader's ability to identify each symbol. The effects of unequal frequency of occurrence of the symbols in an HSR on the legibility of the Murray and Long Gothic fonts was studied in this second experiment. HSR's from Westover Air Force Base were chosen for estimating a set of symbol frequencies which occur in a typical HSR. The method for estimating the relative frequency of occurrence of each symbol is given in Appendix I. For this experiment, the film strips were made up with the numbers of symbols as given in Table XIV of the Appendix.

APPARATUS AND PROCEDURE

The apparatus for this experiment was the same as that for Experiment I with the exception that only two film strips were used; namely, the Long Gothic and Murray strips having the unequal (Westover) frequencies. These film strips are called Westover Long Gothic and Westover Murray in this paper. The symbols were in a random order on the film strips; the order was produced in the way described in Experiment I. The height of the symbols on the film strips was 1/4 inch except for

the Murray Ø and the four Murray cloud-cover symbols on the Westover Long Gothic film strip. The ratio of the height of these Murray symbols to the height of the Long Gothic symbols on the Westover Long Gothic film strip was 0.87. This ratio was also 0.87 on the Long Gothic film strip in Experiment I.

On the Westover Murray film strip, the ratio of symbol height to stroke-width was 16 to 1. On the Westover Long Gothic film strip, the ratio of the symbol height to stroke-width was 19 to 1 for the Long Gothic symbols and 18 to 1 for the Murray symbols. (The Long Gothic film strip used in Experiment I had a ratio of symbol height to stroke-width of 18 to 1 for the Long Gothic symbols, and 16 to 1 for the Murray symbols. The Murray film strip used in Experiment I had a ratio of symbol height to stroke-width of 16 to 1.)

The experimental procedure and the subjects were the same as for Experiment I. The number of symbols shown to a subject at each session was 117, and the subject was given a short rest of about a minute after he had seen thirty symbols, dividing the session into quarters. Each film strip was used at each brightness setting (8, 6, and 5 foot-Lamberts in that order) making a total of six sessions for each subject.

The subjects were told that the symbols would appear with unequal frequencies and which symbols would not be seen at all. The symbols which would not be seen were covered in the photographic prints given to the

subjects for reference during each session. The subjects were told that they would be asked to name another symbol if they called one of those not included.

RESULTS AND CONCLUSIONS

The total number of errors made by the three subjects for the Westover film strips at the three symbol brightness values is given in Table VIII. (For each entry, the number of errors is from 351 symbols shown to the subjects.) To test the hypothesis that the total number of errors was the same for both fonts, a χ^2 test was made on these totals (75 and 58) and was not statistically significant ($\chi^2 = 2.17$, $0.10 < p < 0.20$). Therefore, for the Westover frequency of occurrence, the total number of errors made is assumed to have been the same for the Long Gothic and Murray fonts.

In both fonts, for the Westover frequency of occurrence of the symbols, there was an increase in the number of errors with decreasing brightness. This increase in the number of errors from the 8 foot-Lamberts to the 5 foot-Lamberts brightness value was about the same for both fonts (3 times for Long Gothic and 4 times for Murray), and can be seen in Table VIII.

> Conclusion 1. If the number of errors made is the only consideration, then no reliable difference between the Long Gothic and Murray fonts is apparent

Table VIII

The Total Number of Errors Made by all Three Subjects at Three Brightnesses For the Two Fonts Having Symbols Occurring With the Westover Frequency (The total number of symbols shown at each brightness value was 351.)

Foot-Lamberts	Long Gothic	Murray
8	12	7
6	25	21
5	38	30
Σ	75	58

when the symbols have the Westover frequency of occurrence. Similarly, for this Westover frequency, the effect of decreasing the brightness is the same for both fonts.

A more detailed study was made of the distribution of the errors for both fonts when the symbols occurred with the Westover frequency. The confusion matrices showing these error distributions at the 5 foot-Lamberts brightness setting are in Tables IX and X. The errors were well spread out among the symbols, although the weather symbols accounted for 32 percent of the errors in the Long Gothic font and 23 percent of the errors in the Murray font.

Conclusion 2. It is concluded that there are no outstanding differences in the legibility of the Long Gothic and Murray fonts when the symbols occur with the Westover frequency, but that the four weather symbols are not acceptably legible and must be redesigned. This will be discussed later.

The main purpose of this second experiment was to see if the unequal frequency of occurrence of symbols in a typical HSR would affect their legibility. The results from this experiment were compared with the results of Experiment I. Figure 7 shows the percent error for each

font at the three symbol brightness values. The solid-line curves show the results from Experiment I (referred to earlier) and the dashed-line curves show the results from Experiment II. The percent error was less for the Long Gothic and Murray fonts when the symbols have the Westover frequency of occurrence. Figure 7 and the discussions leading to conclusion 2 of Experiment I and conclusion 1 of Experiment II show that the effects of decreasing the brightness were less for the Westover frequency of occurrence than for the equal frequency of occurrence of the symbols (7 times for equal frequency and between 3 and 4 times for the Westover frequency).

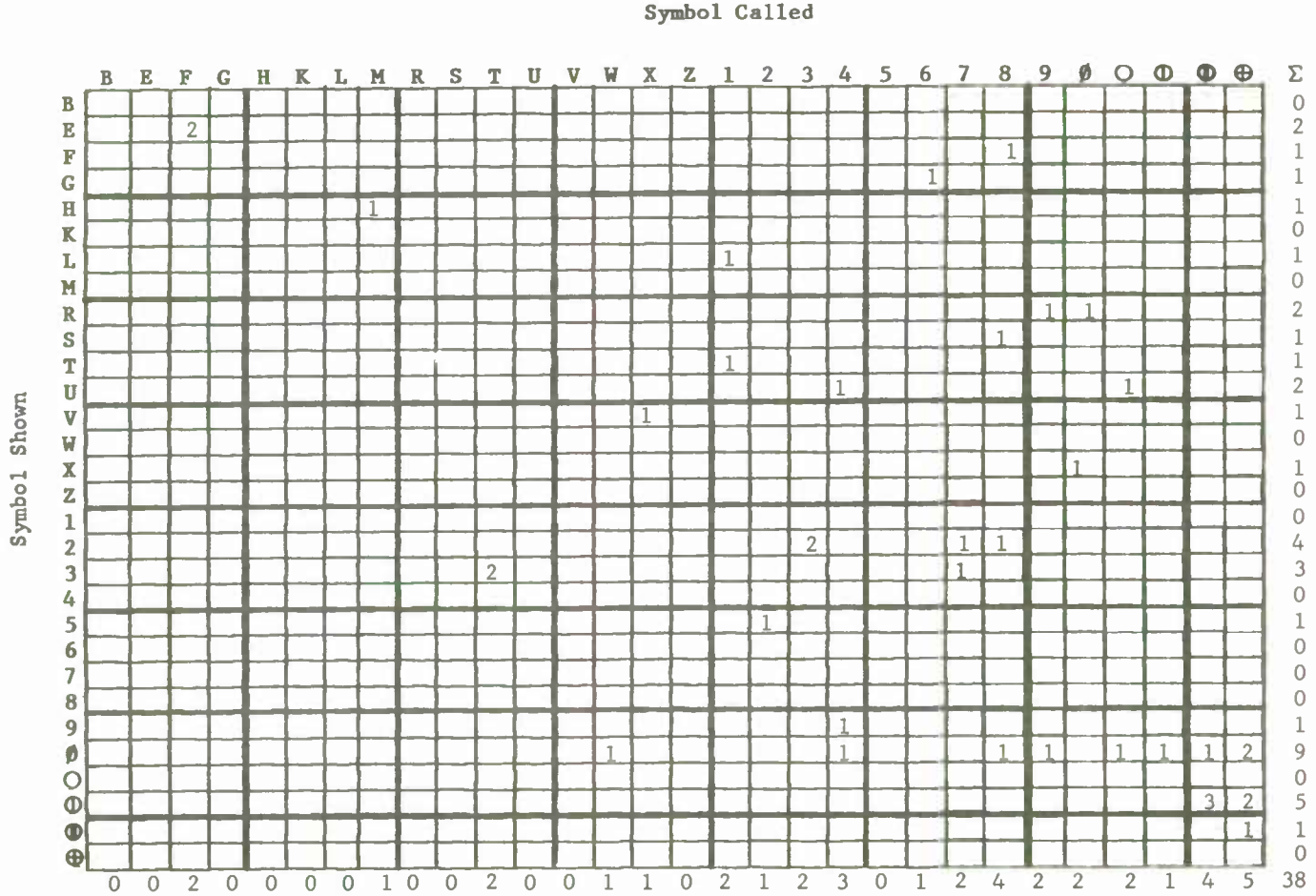
> Conclusion 3. It is concluded that the unequal Westover frequency of occurrence of the symbols reduces the total errors and reduces the effects of decreasing brightness for the Long Gothic and Murray fonts compared to the errors made when the symbols in these two fonts are shown with equal frequencies.

DISCUSSION AND RECOMMENDATIONS

From the results of Experiment I, both the Long Gothic and Murray fonts appear unsuitable where the symbols occur with equal frequency, or nearly so. Some of the alphanumeric symbols could be modified to

Table IX

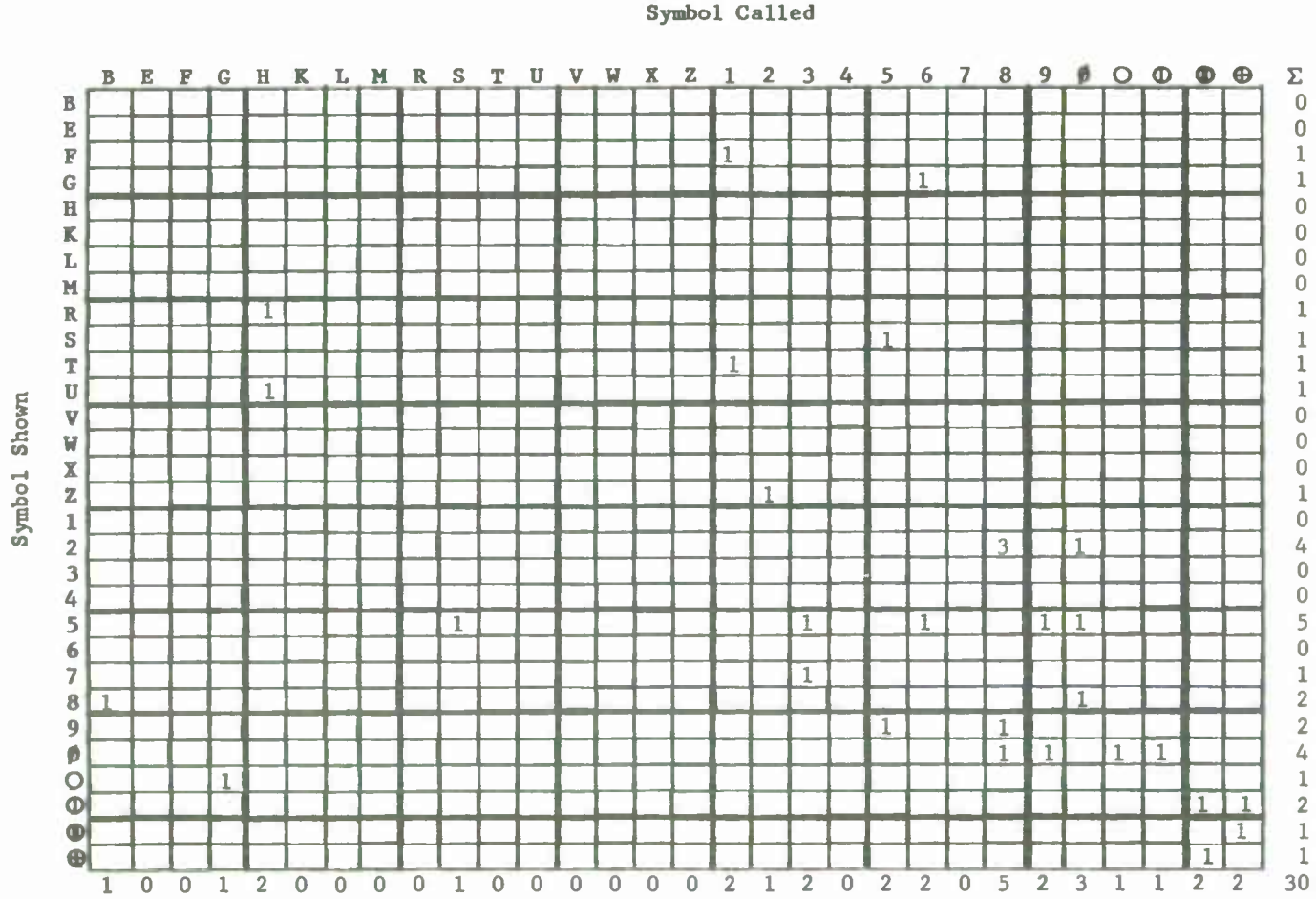
Westover Long Gothic at 5 Foot-Lamberts Symbol Brightness (3 Subjects)



$\frac{38}{351}$ (11% Error)

Table X

Westover Murray at 5 Foot-Lamberts Symbol Brightness (3 Subjects)



$\frac{30}{351}$ (9% Error)

avoid some of the confusions shown in Tables V and VI. Other studies have tried to develop a more legible set of alphanumerics, and one such font is called the Lincoln/MITRE (L/M) font.[4] Improvements in the legibility of alphanumerics used in HSR's may reasonably be expected if the symbols were similar to those in the L/M font. Of course, Experiment II showed that the unequal (Westover) frequency of occurrence of the alphanumerics provides better performance in identifying them. On the other hand, the four weather symbols gave consistently high error, and thus the most obvious improvement in the legibility of the Long Gothic and Murray fonts would result from less confusing weather symbols.

That the weather symbols present a special problem is made clearer by recalling that a characteristic of the HSR is its strict adherence to a fixed format. The four weather symbols appear in only one section of the HSR, and are therefore unlikely to be confused with alphanumerics. The effects of the format on accuracy of symbol identification in an HSR will be the subject of later work, but the present two studies have already indicated that the symbols in a given section will be confused with each other. The four weather symbols are a good case in point.

Confusions among the weather symbols are operationally important and should be avoided. The symbols ⊕ and ◍ indicate a ceiling cloud layer, and the symbol ⓘ indicates a nonceiling cloud layer. There are

minimum ceiling heights for flight under Visual Flight Rules (VFR), Instrument Flight Rules (IFR), and for take-offs and landings made with various instrument systems guiding the pilot. Possible confusions between ⓘ and either ⓓ or ⊕ mean possible confusions between flight rules and should be avoided.

The four weather symbols should be modified, and the new symbols tested for low error and low intersymbol confusions. Symbol design changes are not offered here because no tests have been made. Speculative symbol changes would be premature, anyway, until the results of the television study have been obtained.

The design and testing of new symbols for HSR's are part of the series of studies discussed at the beginning of this paper. Modifications to the symbols will require that all weather and flight personnel learn the new symbols. The problems involved in the learning process are considered to be less important than the problems created by confusions and errors made in interpreting weather reports for flying operations.

G L Bell

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APPENDIX I

ESTIMATION OF THE RELATIVE FREQUENCY OF OCCURRENCE OF SYMBOLS IN TELETYPED WEATHER REPORTS FROM WESTOVER AIR FORCE BASE

This appendix describes how an estimate of the frequency of occurrence of the symbols was obtained for the Hourly Sequence Reports (HSR's) from Westover Air Force Base. This estimate of symbol frequencies was made for part of a series of studies on the legibility of teletype symbols in HSR's which are televised. It was made in two parts because the information was not available from a single source. Part I gives the frequency count made from seven years of data stored on magnetic tape. Part II gives the estimate of the count of some symbols which could not be counted in Part I and also gives the numbers of the symbols to be put on the film strip used in the experiment.

When a weather observer at a United States Air Force base reports the weather conditions, he fills in a standard form, WBAN-10, which is sent to the Data Processing Division*, where some of the information is put on magnetic tape for a permanent record. Figure 8 shows the form of the magnetic tape records which are in a code called the "magnetic tape code." (The magnetic tape format and code are given in the ETAC* Reference Manual TDF 14.) The weather observer extracts some of the

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* Data Processing Division, Environmental Technical Applications Center (ETAC), USAF, Asheville, North Carolina.

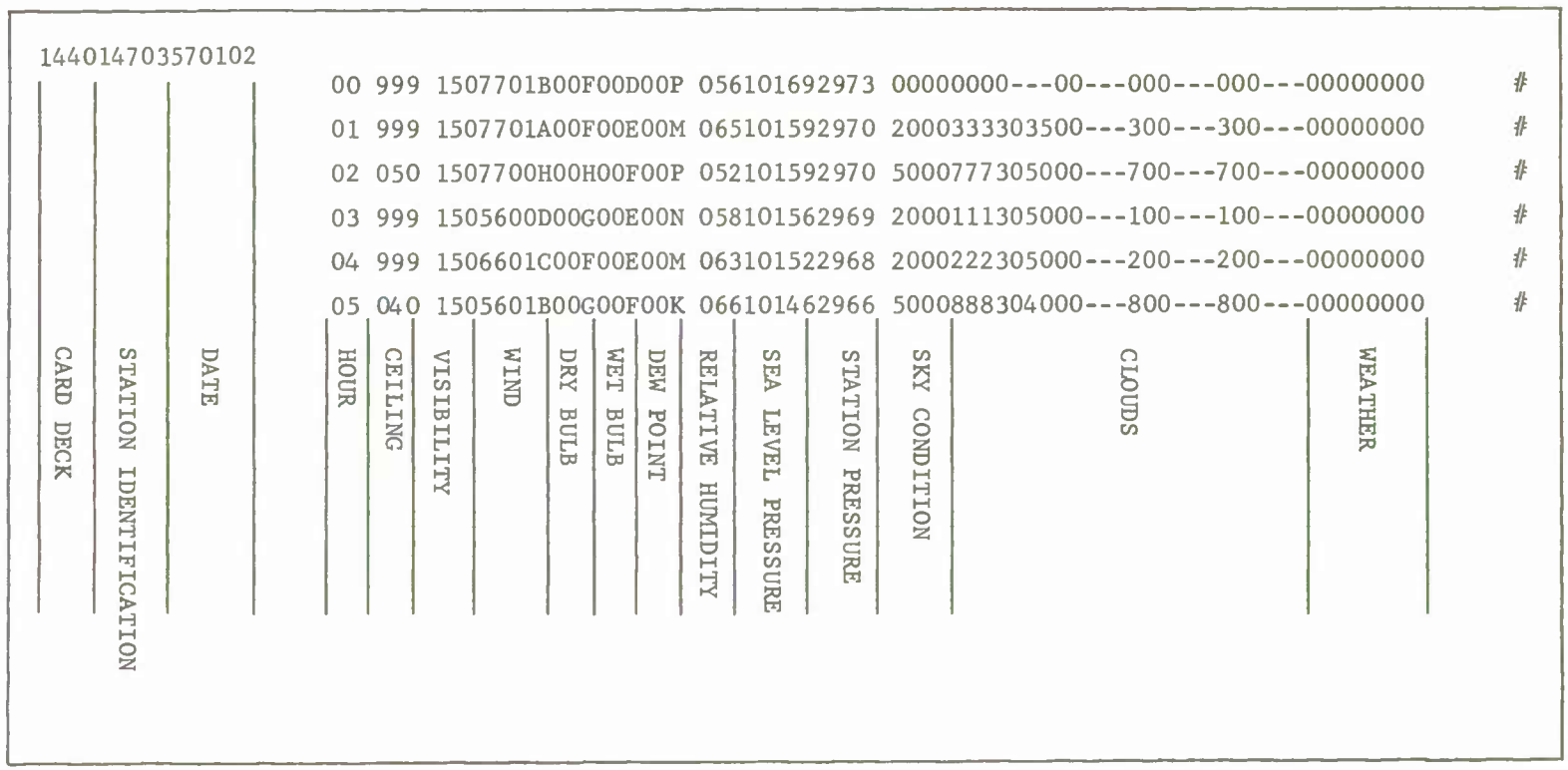

Figure 8. Magnetic Tape Form

information from WBAN-10 for making up the corresponding HSR. Figure 9 shows a group of HSR's where each line is the report from one airfield, and where each HSR is written in a code called the "teletype code." (The HSR format and the teletype code are given in the Manual of Surface Observations (WBAN) Circular N.) Some information given in the HSR's is not given in the magnetic tape records, and vice versa. The HSR's are not stored for permanent record although copies of the WBAN-10 forms are kept at the airfield for several years.

As seen in Figure 9, the HSR's consist of a station identification, the weather report, and coded remarks. Some of the sections in the weather report are separated by a slant line, /. The station identification code is a three-letter word for the name of the air base. The coded remarks can include additional detail about the weather reported in the weather sections, and nonmeteorological detail about field conditions and radio facilities. The weather report is made up with the sections as shown in Figure 9, and is the only part of the HSR which was studied to determine the frequency of occurrence of the typed symbols. The +, -, and / symbols were left out.

PART I

To find the relative frequency of occurrence of the teletype symbols in the weather report of the HSR's was simply a matter of counting the number of times each symbol was used. This was best done over a

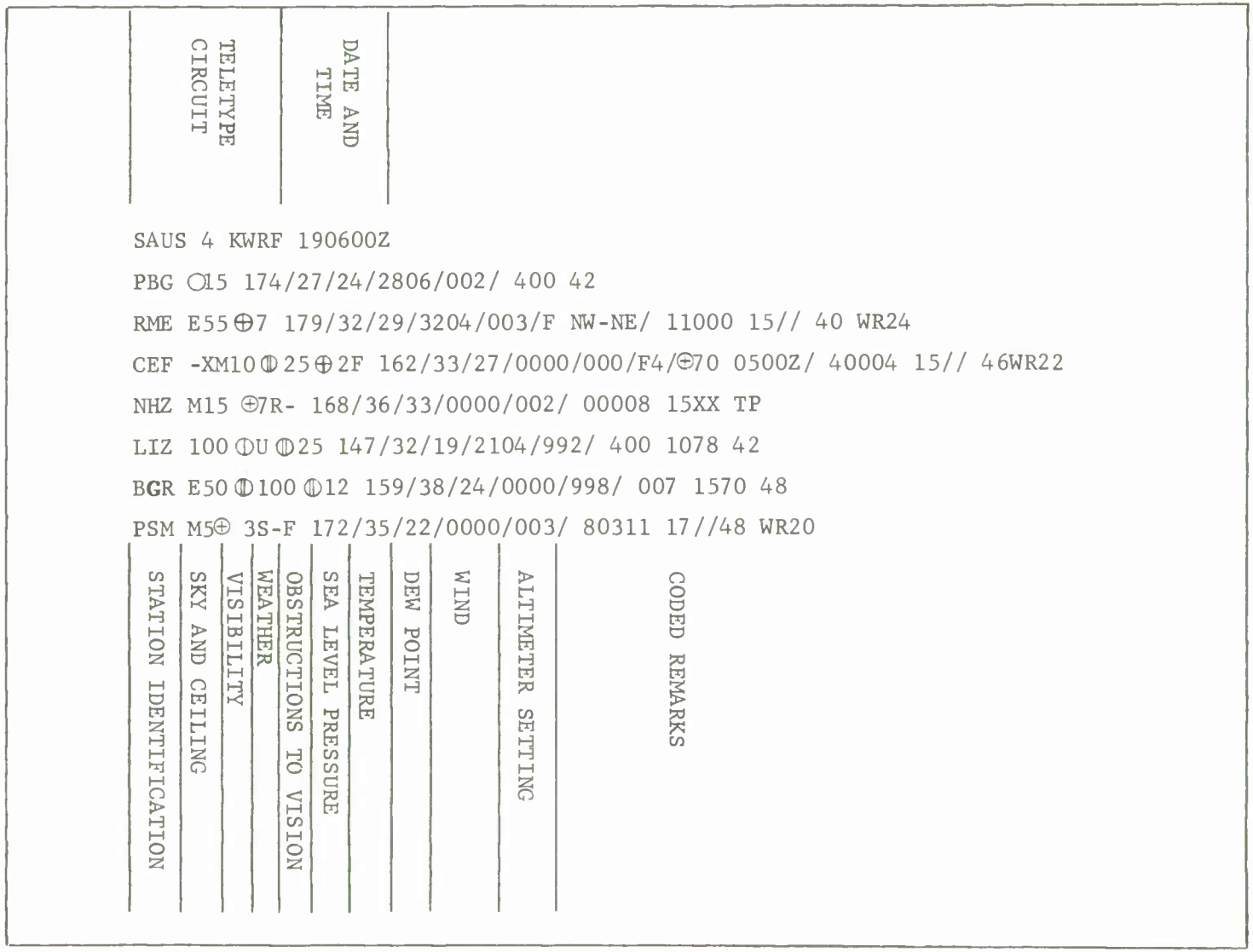

Figure 9. Hourly Sequence Reports and Format

complete year because variations in the weather may affect the frequency of use of the symbols. This work on the reports from Westover used the data for seven years, 1957 to 1963 inclusive, to see if there were differences in the reports from year to year. To count the symbols in HSR's over periods of several years obviously required a computer. The HSR's are destroyed after a few months so that the only records available were those on the magnetic tape or the WBAN-10 forms. The magnetic tape was convenient since it could be used directly on a computer.

The Data Processing Division sent copies of the magnetic tapes for Westover Air Force Base covering the period from 1941 through 1964. After 1949, all of the recordings on the magnetic tapes were made with the format shown in Figure 8, so, to simplify the work, only the tape records made after 1949 were used. The period 1957 to 1963 was an arbitrary selection from these tapes. The problem, then, was to convert the magnetic tape code into the teletype code and to count the teletype symbols produced. Richard T. Jones wrote a computer program to copy the magnetic tapes sent by the Data Processing Division. In copying, the data on the tapes were respaced to make the programming for the code conversions easier. Richard Jones also wrote some parts of the program for the IBM 7030 computer which converted the magnetic tape codes to the teletype codes and counted the resulting symbols. This computer program could be used with any of the magnetic tapes recording United States weather data from 1949 to the present, with the exception of the

the Altimeter Setting section which may need to include the correction factor for station altitude if the station is not near mean sea level.

The teletype code is made up with all of the letters of the alphabet except J and O, with all of the numerals, and with four special symbols, ○, ⏀, ⏁, and ⊕. The magnetic tape code is made up with all of the letters of the alphabet and the numerals. It was not possible to reconstruct the weather sections of the HSR's from the magnetic tape records exactly because some of the information given in the HSR's is not recorded on the magnetic tape. In each of the following paragraphs, the extent to which the weather sections could be reconstructed from the magnetic tape and how the computer program made this reconstruction are shown. The sections referred to for the magnetic tape reports and the HSR's are shown in Figures 8 and 9.

Sky and Ceiling

This part of the HSR gives some information about each cloud layer and reports the existence of any surface-based obscuration. The types of clouds and obscuration are not given. If the surface-based obscuration completely hides the sky, it is called a full obscuration and is coded X. If the obscuration covers between one and nine-tenths of the sky, it is called a partial obscuration and is coded -X. For each cloud layer, the amount of sky covered by the layer is given by one of four cloud-cover symbols, ⊕ for a completely overcast sky, ⏁ for a cloud

layer which covers six to nine-tenths of the sky, ◑ for one to five-tenths coverage, and ○ for a clear sky. If the cloud layer is reported as a thin layer, a minus sign is placed before the cloud-cover symbol. The height of the cloud layer is given in hundreds of feet. No height is given for a clear sky report or for a partial obscuration.

A ceiling is defined as the lowest layer of clouds which has greater than five-tenths sky coverage and is not classified as thin. A full obscuration is defined as a ceiling layer, and its height is the vertical visibility into the obscuration. There can be only one cloud layer defined as a ceiling for each report. For a ceiling layer, a letter code called the "ceiling classification designator" reports how the height was measured, and there is only one of these symbols in each HSR. If the ceiling height is varying, a letter V is placed after the height given, but only if the height is less than 3,000 feet. For a cirriform cloud layer at an unknown height, the height is coded U for a ceiling and a / for a nonceiling layer.

Similar information is given on the magnetic tape in two sections, the Sky Condition and the Clouds sections. The Sky Condition section gives numerical codes for full or partial obscuration. The Clouds section gives numerical codes for the cloud-coverage and for a cirriform ceiling layer at an unknown height and gives the heights of all the cloud layers in hundreds of feet. The cirriform nonceiling layer at

an unknown height is not given on the magnetic tape. The way in which the ceiling height was measured is not given and, also, there is no code to indicate that the height was varying.

In the Clouds section, the computer program converted the numerical codes into the appropriate one of the four cloud-cover symbols and converted the code for the cirriform ceiling at unknown height into a U. In the Sky Condition section, partial or full obscuration was converted into an X. The figures for the height of cloud layers were counted directly since no conversion was needed. A calculation could be made from the data given on the magnetic tape to determine which cloud layers are thin, but this was not done since the frequency of occurrence of the minus sign was not being counted. The teletype codes which could not be obtained from the information recorded on the magnetic tape were the V for a variable ceiling layer and M, A, R, B, W, D, and E which are the "ceiling classification designators." These will be discussed in Part II.

Visibility

The HSR's give the visibility in miles, and a V indicates that the visibility is variable if it is varying and is less than 3 miles. The magnetic tape has a section for reporting visibility, but it does not report if the visibility is variable or not. A numerical code represents the visibility in miles. The conversion from the numerical code

of the magnetic tape to the value in miles of the HSR's was quite straight-forward. The slant line (/) for fractions of miles was left out in the conversion. The teletype code V, for variable visibility, could not be obtained from the magnetic tape and will be discussed in Part II.

Weather and Obstructions to Vision

In the HSR's, an alphabetical code is used in these two sections with + and - signs indicating heavy and light precipitation. Both these sections are combined on the magnetic tape under the single heading, Weather, as shown in Figure 9. The magnetic tape has a numerical code which could be directly translated into the alphabetical code of the hourly sequence reports. The numerical code also gives the precipitation as heavy or light so that the + or - signs were automatically included in the translation. Although these + and - signs were counted, they were not included in the final list showing the relative frequency of occurrence for each symbol. One code which is available on the hourly sequence report which is not given on the magnetic tape is EW, which stands for sleet showers. Sleet (E) and sleet showers (EW) are considered to be the same in the magnetic tape coding. This difference in coding is discussed in Part II.

Sea Level Pressure

The HSR's give the tens, units, and tenths of millibars only. For example, a pressure of 1014.6 millibars is printed as 146 on the teletype report. The magnetic tape record has the complete number and in the example given above would record 10146. The last three numbers were the ones counted in the computer program. The conversion to the teletype code was complete for this section.

Altimeter Setting

The HSR's give the units, tenths, and hundredths of inches of mercury. For example, an altimeter setting of 29.97 inches Hg is given as 997. This section is not given on the magnetic tape. The Station Pressure is given in inches of mercury and records the complete number. The altimeter setting can be obtained from the station pressure by correcting for the station altitude above mean sea level. In this study, the data were from Westover Air Force Base which is 245 feet above mean sea level. The station pressure was not corrected to altimeter setting because the difference is small for this Air Base altitude and the last three numbers for the station pressure were counted as the altimeter setting values.

Temperature and Dew Point

The HSR's give the number for the temperature in degrees Fahrenheit with a minus sign if the temperature is below zero. The magnetic tape

section corresponding to this is called the Dry Bulb section. The temperature sign + or - is superimposed on the units position of the temperature. The + or - sign was separated from the number in the conversion program and the numerals and the minus signs were counted. The minus signs were counted, but were not included in the final list showing the relative frequencies of symbol occurrence. The Dew Point section is similar to the Dry Bulb section, and the conversions were made in the same way. Therefore, for both sections, the conversion from the magnetic tape code to the teletype symbols was complete.

Wind

The HSR's have four numbers in this section. The first two numbers give the wind direction to the nearest ten degrees and the last two numbers give the speed of the wind in knots. For example, a wind from 180 degrees at 3 knots is written as 1803 and a wind from 70 degrees at 13 knots is written as 0713. For gusts or squalls, a G or Q is placed after the numbers followed by the peak speed of the gust or squall. Calm conditions are given as ØØØØ.

The Wind section on the magnetic tape has two parts, the wind direction and the wind speed. The wind direction is given as a numerical code corresponding to the sixteen points of the compass, and the wind speed is given in knots with a + sign superimposed on the units position. Calm conditions are reported with zeros in both parts. The computer

program separated the + sign and counted the numbers for the wind speed section adding a zero for speeds less than 10 knots. For example, a speed reported as 4 knots was recorded as Ø4 knots. A conversion from the 16 points of the compass to tens of degrees had to be made for the wind direction as shown in the following list.

Direction	corresponds to	Degrees
N		350, 360, 010
NNE		020, 030
NE		040, 050
ENE		060, 070
E		080, 090, 100
ESE		110, 120
SE		130, 140
SSE		150, 160
S		170, 180, 190
SSW		200, 210
SW		220, 230
WSW		240, 250
W		260, 270, 280
WNW		290, 300
NW		310, 320
NNW		330, 340

The program made an even distribution between the two or three values which are represented by one point of the sixteen points of the compass as given in the list, and the numbers in the hundreds and tens positions of the degrees were counted.

There is no record of gusts or squalls in the Wind section on the magnetic tape and, therefore, it was not possible to count the G's or Q's and peak wind speeds which would have occurred on the HSR's. Squalls, rain squalls, and snow squalls are recorded in the Weather section on the magnetic tape and John H. Keating advised that gusts would be associated with the squalls reported in the Weather section. It was decided that, for all types of squalls reported in the Weather section on the magnetic tape, a G would be counted. The code letter Q (squalls) was considered to have zero frequency of occurrence and was left out of the list of symbols being counted. Since Q is used only to record squalls in the Wind section of the HSR, John Keating suggested that these did not occur often enough to be counted in the HSR's from the Westover area.

Summary

The computer program was run on the seven years of data (1957 through 1963) for Westover Air Force Base. The information on the magnetic tape was translated into the corresponding teletype symbols with the exceptions noted in the preceding paragraphs. These exceptions are discussed in Part II.

The results are given in tables showing the frequency count of each symbol in each month, as in Table XI. A further division is made into day and night reports where day is defined as being between 0600 and 1800

hours local standard time throughout the year. Each table covers a four-month period and the '24-hour total' column gives the count for each symbol over the complete period.

The data from the Clouds, Sea Level Pressure, and Station Pressure sections are given once every three hours on the magnetic tape records made after July 1958. The data for the Sea Level Pressure is given once every three hours in the HSR's. All the other sections in the HSR's are given hourly if there is something to report, otherwise the section is coded M. For this study, the frequency count was made for the complete reports only. The magnetic tape records containing all the sections were the ones used for the conversion to the teletype codes. That is, the computer program worked with the data given in every third hourly report on the magnetic tape after 1957.

Table XI shows the frequency count of the teletype symbols taken from data for the first four months of 1962 from Westover Air Force Base. There are three such tables for each year. To get the frequency count for the complete year, the 24-hour totals from each of the three tables were summed. The relative frequency of occurrence for each symbol was calculated as a proportion of the grand total for all the symbols. This was done for each of the seven years of Westover data, and the results are shown in Table XII (equivalent to 8760 HSR's for 1957, 2928 for 1960 and 2920 for 1958, 1959, 1961, 1962 and 1963 each, making a total of 26,288 HSR's).

Table XI

Frequency Count of Teletyped Symbols for the First Four Months of 1962

FREQUENCIES											1962
	Night					Day					
SYMBOL	JAN	FEB	MAR	APR	TOTAL *	JAN	FEB	MAR	APR	TOTAL *	24-Hr. TOTAL
1	333	293	354	298	1278 *	368	299	360	310	1337 *	2615
2	287	255	236	250	1028 *	285	272	236	240	1033 *	2061
3	209	172	222	208	811 *	213	197	222	196	828 *	1639
4	122	107	153	167	549 *	112	123	168	182	585 *	1134
5	187	122	208	189	706 *	170	134	229	245	778 *	1484
6	96	77	114	128	415 *	105	105	112	130	452 *	867
7	75	87	109	100	371 *	104	85	123	117	429 *	800
8	104	107	104	108	423 *	106	91	128	108	433 *	856
9	192	172	205	193	762 *	184	183	205	224	796 *	1558
Ø	460	458	427	431	1776 *	448	415	371	385	1619 *	3395
A	0	0	0	0	0 *	0	0	0	0	0 *	0
B	0	3	0	0	3 *	0	2	1	0	3 *	6
C	0	0	0	0	0 *	0	0	0	0	0 *	0
D	0	0	0	0	0 *	0	0	0	0	0 *	0
E	0	2	0	1	3 *	0	4	2	0	6 *	9
F	14	32	5	17	68 *	13	29	4	15	61 *	129
G	4	6	1	2	13 *	2	6	2	6	16 *	29
H	7	10	5	2	24 *	11	17	6	12	46 *	70
I	0	0	0	0	0 *	0	0	0	0	0 *	0
K	0	1	2	1	4 *	4	3	4	5	16 *	20
L	5	8	1	6	20 *	2	7	3	6	18 *	38
M	0	0	0	0	0 *	0	0	0	0	0 *	0
N	0	0	0	0	0 *	0	0	0	0	0 *	0
P	0	0	0	0	0 *	0	1	0	0	1 *	1
R	4	2	7	19	32 *	9	8	5	15	37 *	69
S	2	24	7	1	34 *	5	27	9	0	41 *	75
T	0	1	0	0	1 *	0	0	0	0	0 *	1
U	29	17	24	19	89 *	44	22	39	36	141 *	230
V	0	0	0	0	0 *	0	0	0	0	0 *	0
W	0	0	0	6	6 *	0	2	0	2	4 *	10
X	6	21	1	2	30 *	9	22	2	4	37 *	67
Y	0	0	0	0	0 *	0	0	0	0	0 *	0
Z	2	5	0	0	7 *	1	5	0	0	6 *	13
○	34	30	41	40	145 *	19	21	35	14	89 *	234
⊖	42	37	49	61	189 *	69	51	77	80	277 *	466
◐	26	10	31	27	94 *	36	23	38	46	143 *	237
⊕	49	55	33	30	167 *	39	50	27	34	150 *	317
TOTALS	2289	2114	2339	2306	9048 *	2358	2204	2408	2412	9382 *	18430

Table XII

The Relative Frequency of Symbol Occurrence for 7 Years

Symbol	1957	1958	1959	1960	1961	1962	1963
1	13.59	13.50	13.06	12.96	12.82	12.99	13.19
2	8.63	7.97	8.82	8.94	8.96	9.71	9.83
3	7.40	7.29	7.51	7.09	7.70	7.52	7.22
4	6.35	6.35	6.05	5.96	6.04	6.40	6.84
5	9.07	9.07	8.09	9.23	8.53	8.87	8.35
6	6.21	6.29	6.64	6.58	6.88	6.16	6.08
7	5.41	5.20	5.50	5.27	5.17	5.14	5.41
8	5.07	4.99	5.04	5.04	4.91	5.04	5.15
9	8.26	8.41	8.48	8.38	8.43	8.42	8.46
Ø	18.95	19.10	18.40	19.01	18.88	18.42	18.00
A							
B		0.02		0.02	0.02	0.01	
C							
D							
E	0.01	0.03	0.02	0.01	0.02	0.02	0.01
F	0.65	0.85	0.91	0.74	0.94	0.72	0.69
G	0.22	0.14	0.20	0.15	0.32	0.26	0.29
H	0.51	0.39	0.65	0.58	0.57	0.62	0.73
I							
K	0.08	0.03	0.07	0.05	0.11	0.10	0.10
L	0.05	0.10	0.06	0.06	0.12	0.12	0.06
M							
N							
P							
R	0.31	0.42	0.46	0.41	0.42	0.39	0.35
S	0.15	0.22	0.13	0.21	0.19	0.21	0.18
T	0.01	0.02	0.03	0.02	0.03	0.02	0.02
U	1.50	1.48	1.65	1.49	1.41	1.38	1.34
V							
W	0.11	0.16	0.25	0.20	0.11	0.09	0.10
X	0.31	0.42	0.60	0.58	0.57	0.33	0.42
Y							
Z	0.01	0.01	0.02	0.02	0.02	0.03	0.02
○	0.84	0.65	0.67	0.83	0.77	1.07	1.10
⊕	3.69	4.18	3.92	3.62	3.11	3.14	3.51
◐	1.44	1.60	1.69	1.59	1.52	1.36	1.42
⊖	1.15	1.12	1.08	0.95	1.42	1.45	1.12

A matrix of the intercorrelation coefficients for the seven years of Westover data was made with a program written by Charles V. Riche. The values were very close to unity, the smallest value being 0.99. This meant that the results from any one year were closely representative of the results from any other year. The frequency of occurrence of each symbol was taken as the total count for the complete seven-year period. The percentage value for each symbol calculated with respect to the total for all the symbols gave the relative frequency of occurrence for each symbol, given as the last column in Table XIII.

PART II

The total number of symbols on the film strip was decided after the results of Part I were seen, remembering that the total number determined the length of the experimental sessions described in the main text. The list of symbols on the film strip was made up using the relative frequency values in Table XIII rounded to the nearest whole number except for those symbols with a relative frequency less than 2.5 percent. One symbol was put on the list for any symbol with a relative frequency less than 0.5 percent and two symbols were put on the list for any symbol with a relative frequency between 0.5 and 2.5 percent.

Table XIII

Data on Frequency of Symbol Occurrence

Symbol	Total Count N Over 7-Year Period	Relative Frequencies ($\frac{N}{\Sigma N} \times 100\%$)
1	69182	13.25
2	46432	8.90
3	38585	7.39
4	32879	6.30
5	46020	8.82
6	33214	6.36
7	27796	5.33
8	26318	5.04
9	43702	8.37
Ø	97814	18.74
A	1	Ø
B	53	0.01
C	1	Ø
D	1	Ø
E	83	0.02
F	3953	0.76
G	1166	0.22
H	2940	0.56
I	6	Ø
K	395	0.08
L	388	0.07
M	Ø	Ø
N	Ø	Ø
P	6	Ø
Q	Ø	Ø
R	1957	0.37
S	926	0.18
T	101	0.02
U	7697	1.47
V	Ø	Ø
W	719	0.14
X	2245	0.43
Y	Ø	Ø
Z	76	0.01
◯	4402	0.84
⌀	18900	3.62
⌀	7836	1.50
⊕	6139	1.18
	ΣN = 521933	

The teletype symbols which could not be obtained from the magnetic tape were the V for a variable ceiling or a varying visibility, the W from the EW for sleet showers, the Q for wind squalls, and the ceiling classification designators, M, A, R, B, W, D, and E. The Q was discussed in Part I and was given a frequency count of zero. From the results in Table XIII, the number of times E was counted was only 83 in a seven-year period. Since the E counted from the magnetic tape corresponded to both E and EW in the HSR's, it was assumed that the number of W's, which would have appeared on the HSR's as part of the code EW, was small enough to be ignored and would not contribute to the total count for W.

An attempt was made to estimate the count for the other symbols listed above by reading some of the Westover HSR's. The weather station at Hanscom Air Force Base sent the teletyped HSR's for April 1965. All of the Sky and Ceiling and Visibility sections of the Westover HSR's given in these April reports were read. V was not used in these HSR's, but it was decided that no assumption could be made about the use of V, since variable low ceilings and variable visibilities may be seasonal. (V is used only for a variable ceiling less than 3,000 feet or a variable visibility of less than 3 miles.) It was not possible to make an estimate of the number of times V was used in the Westover HSR's from any of the information at hand, but it was decided that V should be included. One V was added to the list of symbols on the film strip.

In the April HSR's, the ceiling classification designators, as usual, show how the ceiling height was determined by the weather station. It was assumed that the same procedures would always be used at Westover, and that the ceiling classification designators in the April reports would represent those occurring at any other time of the year. From these reports and the estimates made in Part I, the frequency of occurrence of the ceiling classification designators was estimated.

For example, in the 720 HSR's for April, there were 47 R's, 140 M's, 130 E's, and 8 W's. The R, M, and E were always associated with ceilings consisting of cloud-layers above the surface. A ceiling is defined as the lowest cloud-layer which is coded ⏀ or ⊕. In some HSR's, there is more than one cloud-layer coded ⏀ or ⊕ with some layers coded -⏀ or -⊕. From Part I the relative frequency of occurrence of ⏀ and ⊕ together was 2.68 percent. Therefore, the relative frequencies of R, M, and E taken together is less than 2.68 percent. Since, from Part I, the relative frequencies of R, M, and E were 0.37 percent, 0 percent and 0.02 percent respectively, it was assumed that the relative frequencies of R, M, and E were each less than 0.5 percent. One R, one M, and one E were put on the film strip.

The April HSR's had no A's, B's, or D's. From Part I, the relative frequencies of A, B, and D were 0 percent, 0.01 percent and 0 percent. The A and D were omitted from the film strip, and one B was included.

The letter W was always associated with a full obscuration, coded X, in the April reports. The relative frequency of occurrence of X in Part I was 0.43 percent which includes both X and -X. Also from Part I, the relative frequency of W was 0.14 percent. Assuming that W would be used with all codes X, the relative frequency of occurrence of W in general must be less than 0.5 percent. Therefore, one W was put on the film strip.

The numbers of each symbol appearing on the film strip are shown in Table XIV. The total is 117 because the equipment made it convenient to have an odd number on the film strip. A zero was added to reach the desired total with the smallest possible change in the relative frequency of occurrence of a symbol, zero being the most frequent.

Table XIV

Numbers of Symbols on Film Strip

Symbol	Symbol Count On Film Strip
1	13
2	9
3	7
4	6
5	9
6	6
7	5
8	5
9	8
Ø	20
A	Ø
B	1
C	Ø
D	Ø
E	1
F	2
G	1
H	2
I	Ø
K	1
L	1
M	1
N	Ø
P	Ø
Q	Ø
R	1
S	1
T	1
U	2
V	1
W	1
X	1
Y	Ø
Z	1
○	2
⊕	4
⊕	2
⊕	2

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13. ABSTRACT

The first two studies are reported from a planned series of studies to obtain legibility data on teletyped hourly sequence weather reports. In the first study, subjects were asked to identify symbols, shown singly in a random order with the symbols occurring with equal frequencies. The two teletype fonts, Murray and Long Gothic, were compared with a standard Leroy font. The second study used the teletype fonts only, and the subjects identified symbols shown with symbol frequencies similar to those in typical hourly sequence reports. For these experimental conditions, the teletype fonts were not as legible as the standard Leroy font although the symbol frequencies found in typical hourly sequence reports improved the subjects' reading performances.

This is the final report of Project 7030.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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